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Executive Summary

This deliverable provides information about the state of the art in the Electrical Vehicles (EV) and Electrical Vehicle Supply Equipment (EVSE) market with the aim to assess the functionalities of different products and their interoperability.

The e-mobility market is continuously developing and – as a consequence – new approaches/solutions regarding EVs and EVSE technologies are continuously introduced. In this report EV technologies are described with special attention focused on EV components and systems related to battery charging. Market available products and their main characteristics (that might affect interoperability) are assessed.

This report also presents the state-of-the-art in EVSE technologies, including charging equipment and charging technologies. Possible issues related to the connection between the EVSE and the electricity grid and the impact of the charging process on the electricity network operation is also considered and assessed from a Distribution System Operator (DSO) perspective. The most likely scenarios of EV usage are defined based on the analysis of user behaviour patterns. These scenarios served as a reference for the analysis of functionalities of different system that have to interoperate. The functionalities are assessed taking into account issues such as safety and protection, charging procedure and communication between different actors.

Separate parts of this report are devoted to Smart Charging and Vehicles-to-Grid services (V2G). In these parts, various e-mobility future scenarios and their impact on the infrastructure are considered. Envisioned Smart Charging functionalities are described regarding user services as well as distribution grid services and Smart Charging requirements are specified from both EV user and grid operator point of view. Special attention is paid on communication issues, as these seem to be the most challenging ones to resolve.

A major part of this report considers the identification of needs related to the interoperability between EVs and the electrical power system (i.e. EVSE and related interaction with the (smart) grid). The followed approach was based on the Smart Grid Reference Architecture Methodology (SGAM).

In summary, this report provides the following contributions:

- review of market available EV and EVSE products,
- analysis of future scenarios related to e-mobility,
- assessment of functionalities of different components available in present and future systems,
- identification of needs for interoperability between EV components and electrical power system.

This report will be used as a reference document for further elaboration of the interoperability needs in Work Package 2 (Integration and alignment of testing methods with standards) and Work Package 5 (New and unified test facilities). The deliverable does not deal with communication aspects at the information level, what is a subject of the deliverable D 3.1.

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Abbreviations and Acronyms

Table 1. Acronyms

AAA	Authentication, Authorization, Accounting
AC	Alternating Current
ACEA	European Automobile Manufacturers Association
AMI	Advanced Metering Infrastructure
AP	Access Point
ATM	Abstract Test Method
B2B	Business to Business
BEV	Pure Battery Electric Vehicles
BMS	Battery Management System
CEM(S)	Customer Energy Management (System)
CEN	European Committee for Standardization
CENELEC	European Committee for Electrotechnical Standardization
CIM	Common Information Model
CIS	Customer Information System
COSEM	COmpanion Specification for Energy Metering
CS	Charging Station
CSF	Context Setting Framework
DC	Direct Current
DER	Distributed Energy Resources
DLMS	Device Language Message Specification
DLMS UA	Device Language Message Specification User Association
DMS	Distribution Management System
DoD	Depth of Discharge

DR	Demand Response
DSM	Demand Side Management
DSO	Distribution System Operator
EAP	Enhanced Authentication Protocol
EC	European Commission
EMC	Electromagnetic Compatibility
EMG	Energy Management Gateway
EMS	Energy Management System
EMSP	Electric Mobility Service Provider
ENTSO-E	European Network of Transmission System Operators for Electricity
EREV	Extended Range Electric Vehicle
ESA	Electrical and electronic sub-assemblies
ESO	European Standard Organisations
ETSI	European Telecommunications Standards Institute
EU	European Union
EUT	Equipment Under Test
EV	Electric Vehicle
EVSE	Electric Vehicle Supply Equipment
EVSEO	Electric Vehicle Supply Equipment Operator
EVSEO CC	EVSE Operator's Control Centre
EVSP	Electric Vehicle Service Provider
FACTS	Flexible AC Transmission System
FAT	Factory Acceptance Test
FEV	Fully Electric Vehicle
FLISR	Fault Location, Isolation, System Restoration

GIS	Geographic Information System
GUC	Generic Use Case
GWAC	GridWise Architecture Council
HAN	Home Area Network
HES	Head End System
HEV	Hybrid Electric Vehicle
HL-UC	High Level Use Case
HMI	Human Machine interface
HV	High voltage
ICT	Information and Communications Technology
ID	Identification
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IFS	Interoperable Function Statement
IM	Induction motor drives
IOP	Interoperability
IT	Information Technology
ITS	Intelligent Transport Systems
IUT	Implementation Under Test
LBC	Load Balance Control
LNAP	Local Network Access Point
LV	Low Voltage
MADES	Market Data Exchange Standard
MV	Medium Voltage
NAN	Neighbourhood Area Network
NFC	Near Field Communication

NIC	Network Interface Controller
NMI	Human Machine interface
NNAP	Neighbourhood Network Access Point
OEM	Original Equipment Manufacturer
OIS	On-board Information System
OMS	Outage Management System
OSI	Open Systems Interconnection (model)
PCC	Point of common coupling
PEV	Hybrid-electric vehicles
PHEV	Plug-in Hybrid Electric Vehicle
PLC	Power Line Communication
PM BLDC	Permanent magnet brushless DC motor drive
PUC	Primary Use Case
PWHC	Partial weighted harmonic current
PWHD	Partial weighted harmonic distortion
PWM	Pulse-Width Modulation
RCD	Residual Current Device
REESS	Rechargeable Energy Storage Systems
RES	Renewable Energy Resources
RFID	Radio-frequency identification
RMS	Root mean square
RTU	Remote Terminal Unit
SA	Secondary Actor (not involved directly in the charging process)
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart Grid Architecture Model
SG-CG	Smart Grid Coordination Group

SG-CG/SP	Smart Grid Coordination Group - Sustainable Processes
SGIMM	Smart Grid Interoperability Maturity Model
SNMP	Simple Network Management Protocol
SOA	Service Oriented Architecture
SOC	State of charge (in battery energy storage)
SRM	Switched reluctance motor drive
SUT	System Under Test
TC	Test case
TCO	Total Cost of Ownership
TCP/IP	Transmission Control Protocol/Internet Protocol
TD	Test description
TF	Task Force
THC	Total Harmonic Current
THD	Total Harmonic Distortion
TSO	Transmission System Operator
UC	Use Case
UCAIug	UCA International Interest group
UCMR	Use Case Management Repository
UI	User Interface
V2B	Vehicle To Building
V2G	Vehicle To Grid
VPN	Virtual Private Network
VPP	Virtual Power Plant
WAN	Wide Area Network
WP	Work package
WPT	Wireless power transfer systems

1 INTRODUCTION

1.1 Electric mobility

Electric Vehicles (EVs) are an important part of the strategic development of the automotive industry. It is strictly related to the European Union (EU) policy aimed at the energy efficiency and tackling climate change (reduction of CO_2 emissions). The document "2050 Transport Strategy Plan" [1], published by the European Commission (EC) in 2011, and adopted by the European Parliament, assumes gradual substitution of combustion cars by EVs (especially in case of corporate fleets).

Simultaneously, the market of e-mobility is continuously developing, which is evidenced by different approaches and innovative solutions that manufacturers introduce into the market launching EVs and Electric Vehicle Supply Equipment (EVSE) technologies. As a result, EV users/owners might face interoperability problems that may significantly affect functionality of his/her vehicle. In order to support the widespread adoption of EVs in Europe, it is imperative that EVs and EVSE (needed to allow the charging and additional services) are compatible to some extent. Thus, there is a need to guarantee and to confirm the interoperability of present and future EV systems.

The term Interoperability, used in this document, means the ability of two or more networks, systems, applications, components or devices from the same vendor, or different vendors, to perform required functions and services. The interoperability must be performed at different levels:

- energy transfer between EV and EVSE,
- safety for EV, EVSE and involved people,
- information exchange that is necessary for controlling energy transfer, payment and accounting between actors operating within the system.

The performance and interoperability of all EV and EVSE systems need to be assessed from the perspectives of the mentioned levels. This will ensure an option for the whole system to be able to offer charging and other services, which will allow for the creation of sustainable new business models.

Many initiatives have been undertaken in recent years in order to promote the widespread implementation of EVs in Europe and to reduce all kind of technical, regulatory, commercial and/or political barriers. As a response to EC mandates M/468 [2], [3], M/453 [4] and M/490 [5], CENELEC Smart Grid Coordination Group (SG-CG) and E-Mobility Coordination Group (EM-CG) were established, within which the next working groups were appointed, such as the Group for Smart Charging (GSC) and the Working Group for Interoperability (WGI) with experts from different technical domains. The tasks for these bodies comprise the coordination of necessary activities to ensure the integration of different systems within the existing regulatory and standard framework in the scope of e-mobility.

Furthermore, numerous European research and demonstration projects have been implemented, addressing different problems related to EV and EVSE, and providing outcomes that can be used or have already been used in the processes of EV integration with electrical power systems. Some of these projects developed e-mobility solutions that have the potential to achieve sustainable results in the use of renewable and non-polluting energy sources, which supports the achievement of the EU's ambitious climate goals.

For example, the Green e-Motion project recommends a selected set of standards to be used for electro mobility systems. The G4V and the Smart V2G projects analyse the impact and possibilities of a mass introduction of EVs to the electricity networks in Europe. These projects also consider the connection of EVs to the grid by enabling a controlled flow of energy and power through a safe, secure, energy efficient and convenient transfer of electricity and data. Another project - Power Up is focused on the potential vehicle to grid (V2G) applications.

COTEVOS makes use of the European and worldwide projects and integrates their findings and achievements in many aspects, such as: smart grid and V2G potentials, the interoperability issues or interoperability needs assessment, e-mobility future scenarios and many more.

1.2 COTEVOS project

COTEVOS aims to develop optimal structures and capacities to test the conformance, interoperability and performance of different systems to be included in the infrastructure for Smart Charging of Electric Vehicles. Based on the partners' contrasted experience and a decade of collaboration around the facilities, standardization and research infrastructures for Distributed Energy Resources (DER) and aligned with ongoing standardization development under M/453, M/468 and M/490 (CENELEC SG-CG, E-Mobility Smart Charging WG among others), COTEVOS will address key issues such as the cross-national transparency, the interaction between grid infrastructure and vehicles and the operational reliability, while reducing the time-to-market of equipment, so that they will be available in line with the arrival of electric vehicle. For that purpose, a number of on-going demo projects will be used as a reference.

1.3 Scope of the document

This report (deliverable D1.1) summarizes the results of work performed within Work Package 1 in Tasks 1.1, 1.2 and 1.3. The main goal of the document is to analyse the current and future situation in the scope of EV systems and their interaction with electrical power grid (Tasks 1.1 and 1.2). The report contains a study on implementation of EV and EVSE technologies, engages various prospective business models that include market opportunities, social impact, functionalities and services performed by different systems. The document depicts aspects resulting in different needs and requirements for interoperability. Particular attention is paid to issues related to EV Smart Charging, V2G applications and EMC for EV charging systems.

The specific objectives of the document are the following:

- Analysis of actual and foreseen future potential in EV mobility including EVs and EVSE
- Identification of functionalities of different systems allowing to perform different services
- Study and definition of the reference networks and models to be used for the testing
- Analysis of information exchange, communication and protocols
- Specification of needs for interoperability between EVs and electrical power system

A separate topic, which is also included in the report, is the analysis of existing infrastructure and capabilities worldwide in order to assess the performance of the different systems or applications related to EV charging and any kind of services concerned (Task 1.3).

The results of this report will provide a basis for defining the EVs interoperability needs, which shall be subject to some further analysis in subsequent technical tasks.

1.4 Document structure

The document comprises 11 main Chapters. After the introductory remarks in Chapter 1, Chapter 2 provides the state of the art in e-mobility including EV and EVSE technologies and standardization issues. The summary of this chapter is section 2.5 where the functionalities of different systems are specified. The next Chapter 2.6 describes the potential EV mobility future scenarios leading to the assumptions for some further work within the COTEVOS project.

Chapter 4 deals with Smart Charging and is followed by Chapter 4 in which V2G functionalities are discussed. The structure of both chapters involves the explanation of processes, description of commercially available systems, prospective functionalities and services.

In Chapter 6 user expectations for functionality of charging systems are presented based on the surveys carried out in different countries.

Chapter 7 introduces the methodology for assessing the interoperability needs and uses the SGAM model for this purpose. On the basis of functionalities of different systems identified in Chapters 1-6, the needs for interoperability are identified in chapter 7.5. The interoperability is discussed in different levels, i.e. business and regulation, functions, information and components. Needs for interoperability are listed in the form of a table for selected use cases involving current and future performance of different systems (subchapter 8.7).

Subsequently, Chapter 9 concerns interoperability related recommendations from the energy sector, infrastructure providers and European Automobile Manufacturer's Association (ACEA).

Chapter 10 presents the overview of current infrastructure capabilities at international level on EV integration.

Finally, Chapter 11 contains the conclusions of the document.

2 STATE OF THE ART IN E-MOBILITY

2.1 Standardization

Standardization is one of key factors required to accelerate and facilitate a successful market entry of EV technology. Since EVs are at the frontier of two worlds: electricity and automobility, thus a broad range of features, components and systems need to be standardized. This should make EVs and its infrastructure simpler, cheaper and increase EV systems interchangeability and compatibility.

This subchapter gives an overview of standards that are essential for the operation of an EV-EVSE systems and sustainment of its market penetration.

2.1.1 EU mandates M/468 and M/490

The European Commission has issued several EU standardization mandates. Two of these are especially important for the EV interoperability field, they are:

- M/468,Standardisation mandate to CEN, CENELEC and ETSI concerning the charging of electric vehicles, June 2010,
- M/490 Standardization Mandate to European Standardization Organizations (ESOs) to support European Smart Grid deployment, March 2011

The best starting point is by making public references:

- For the mandate M/468 the home website address is: http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/Management/ElectricVehicles/Pages/default.aspx and the report on 'Standardization for road vehicles and associated infrastructure' is available at [6].
- According to M/468 the Smart Charging is seen as a necessity to optimize the use of the electrical grid for efficient EV charging, while maximizing the use of renewable energy. Since this topic needs further developments and it is therefore addressed by the working group 'Smart Charging' established jointly by the CEN-CLC-ETSI Smart Grid Coordination Group and the CEN-CLC eMobility Coordination Group. The final report is not yet released.
- the website http://www.cencenelec.eu/standards/Sectors/SustainableEnergy/Management/SmartGrids/Pages/default.aspx gives access to documents on:
    - Sustainable Processes [7]
    - First Set of Consistent Standards [8]
    - Reference Architecture [9]
    - Report on standards for information security and data privacy [10].
- New M/490 Working Group has been formed, these will address (documents are not yet ready or publicly released):
    - M/490 - Consistent set of standards
    - M/490 - New applications and Methodology

- M/490 - Interoperability
- M/490 - Information Security

Some of the topics described in the M/468 (relevant for COTEVOS purposes) are already covered in subchapter 2.2 and 2.3, e.g. the different charging modes and overview of functions in electro-mobility data communication.

Another M/490 report gives a lot of information about architecture, use cases, methodology, available standards, etc. In the remainder of this subchapter we will list the most important ones w.r.t. the scope of this COTEVOS project.

The M/490 report: CEN-CENELEC-ETSI Smart Grid Coordination Group – Sustainable Processes, makes the crucial role of use cases clear.

Use cases in M/490 have been collected from a diverse range of stakeholders. The use cases can therefore be considered as essentially describing the functionality and requirements with respect to needs of an array of actors. Actors can be classified as people (their roles or jobs), systems, databases, organizations, and devices involved in or affected by the use case.

Several use cases are available in the M/490 Use Case Management Repository (UCMR). Mapping of the use cases to the business and function layer of the proposed Smart Grid Reference Architecture (SGAM) established by the Working Group Reference Architecture (SG-CG/RA) is a further key element of supporting material to the generic use case analysis.

In subchapter 8.3 Conceptual description - Smart Charging of this M/490 report five EV related use case categories have been identified:

1. WGSP-1100 Uncontrolled charging
2. WGSP-1200 Charging with demand response
3. WGSP-1300 Smart (re- / de) charging
4. WGSP-1400 Ensuring interoperability and settlement
5. WGSP-1500 Manage charge infrastructure

Please note that use cases are not magic bullets. The use case methodology should be seen as being part of a chain of necessary steps towards interoperable solutions. Standardization, technology tracking and reference architecture are also needed as some basis for concrete standardization work like the definition of data models, interfaces, protocols etc.

The M/490 report: CEN-CENELEC-ETSI Smart Grid Coordination Group Smart Grid Reference Architecture mentions: Key is that the SGAM framework consists of five layers representing business objectives and processes, functions, information exchange and models, communication protocols and components. Another framework axis is SGAM Domains (from Bulk Generation to Customer Premises) and SGAM Zones (from processes, fields to enterprise and market).

The M/490 working group “First set of standards” (SG-CG/FSS) [8] is working with an approach centred on breaking down the Smart Grid into systems. This CEN-CENELEC-ETSI Smart Grid Coordination Group First Set of Standards identified about 24 types of Smart Grid systems (one of these are E-mobility systems), more than 400 standard references, coming from more than 50 different bodies.

The document defines interoperability as follows:

> Interoperability shall be envisaged between two or more components of the same system, or between systems.
>
> It means (derived from GridWise Architecture Council (GWAC) work):
>
> - exchange of meaningful information,
> - a shared understanding of the exchanged information,
> - a consistent behaviour complying with system rules, and
> - a requisite quality of service: reliability, time performance, privacy, and security.
>
> Many levels of interoperability can be considered but in all cases smart grids require interoperability at the highest level, i.e. at information semantic level.

The report also mentions the E-mobility System.

> E-mobility comprises all elements and interfaces which are needed to efficiently operate EVs as a flexibility resource in a future Smart Grid system. The Standardization work within the E-mobility domain is currently on-going under the leadership of the E-Mobility co-ordination group (EM-CG), and a working group for Smart Charging was specifically built-up to define a role model, associated use cases and to identify standards for E-mobility. Work results are due by end of 2012.

The first version was available beginning 2013. The more final version at the end of 2013; it is currently getting the final update. It bridges the M/468 and M/490 work in the overlapping area of Smart Charging. The document defines an E-mobility role in definitions of reference actors and roles in the ENTSO-E role model.

Besides, the SGCG First Set of Standards identified more than 400 standard references, the new M/490 WG Interoperability created an IOP Tool referencing 537 standards, with several selection criteria, including testing (electrical, mechanical, system, conformance, interoperability, and acceptance).

Further the IEC gives an access to a Smart Grid Standards Mapping Tool, see http://smartgridstandardsmap.com/. But this tool is still a draft, for example IEC/ISO 15118 is not mentioned yet.

These two tools should be considered for use in COTEVOS and other EV/Smart Grid related projects and activities.

2.1.2 Standardisation areas

To mitigate the problems related to interoperability of diverse EV/EVSE technologies, standardisation organisations set series of standards to ensure [6]:

- adequate level of safety,
- possibility of charging at homes and in residential areas in adequate domestic socket-outlets and private charging stations,
- affordability and ease of use which involves: cables and plugs and simple and consistent user interfaces,
- interoperability of connectors and billing mechanisms throughout Europe,

- security concerning data privacy, authentication, protection against vandalism and cable theft,
- durability and robustness of charging equipment,
- interoperability and connectivity between the charging station and the EVs,
- secure and reliable communication between components involved in EV charging process and service of the charging station. Interfaces and the overview of actors that can be involved in e-mobility data communication are presented in Figure 1.
- and appropriate consideration of any smart-charging issues with respect to the charging of EVs.

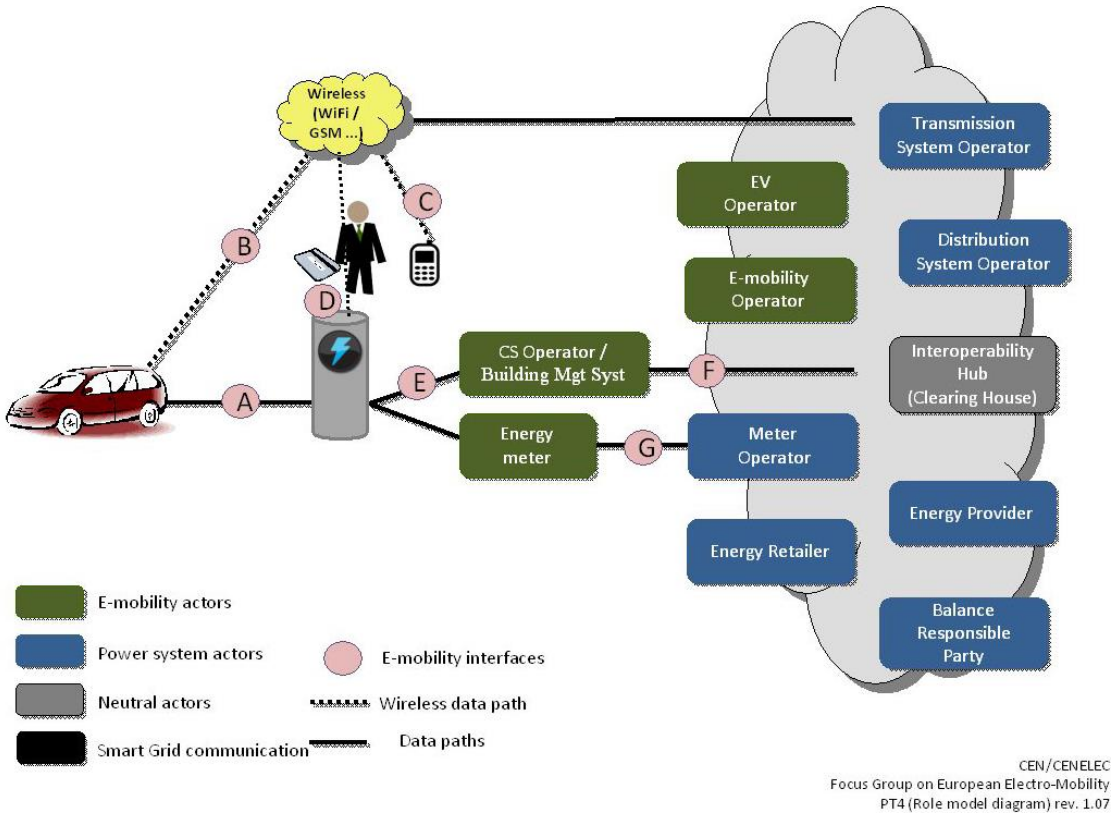


Figure 1. Overview of functions in electro-mobility data communication [6]

Existing EV and EVSE related standards pertain to the four main areas:

- **charging topology:**
  - The main reference documents for conductive charging are the IEC 61851-X family of standards. IEC 61851 applies to the EV as well as to the charging station, e.g. it introduces four charging modes, related to the actual conductive charging infrastructure (see subchapter 2.1.3).
  - The IEC 61980 – applies to EV inductive charging systems, however it is under preparation (see subchapter 2.3.3.2).
    - IEC 61439-5 – describes assemblies for power distribution.
- **communications:**

Communication between the vehicle and the charging station is defined in IEC 61851 and ISO/IEC 15118 standards.

- **charging connectors:**
  Accessories for charging, e.g. the type of connectors/inlet, are defined in IEC 62196 standard.
- **safety/security:**
  Essential safety requirements for the EV, its rechargeable energy storage system, the operational safety of electrical systems, and the safety of persons are covered in the ISO 6469 series. Additionally, the following standards from the field of electrical installations must be observed in order to ensure adequate protection:
  - IEC 61140 – protection against electric shock - common aspects for installation and equipment,
  - IEC 62040 – uninterruptible power systems,
  - IEC 60529 – degrees of Protection Provided by Enclosures,
  - IEC 60364-7-722 – applies to circuits for EV supply using charging modes 1 to 4.

Figure 2 presents a graphic interpretation with listed standards and related objectives.

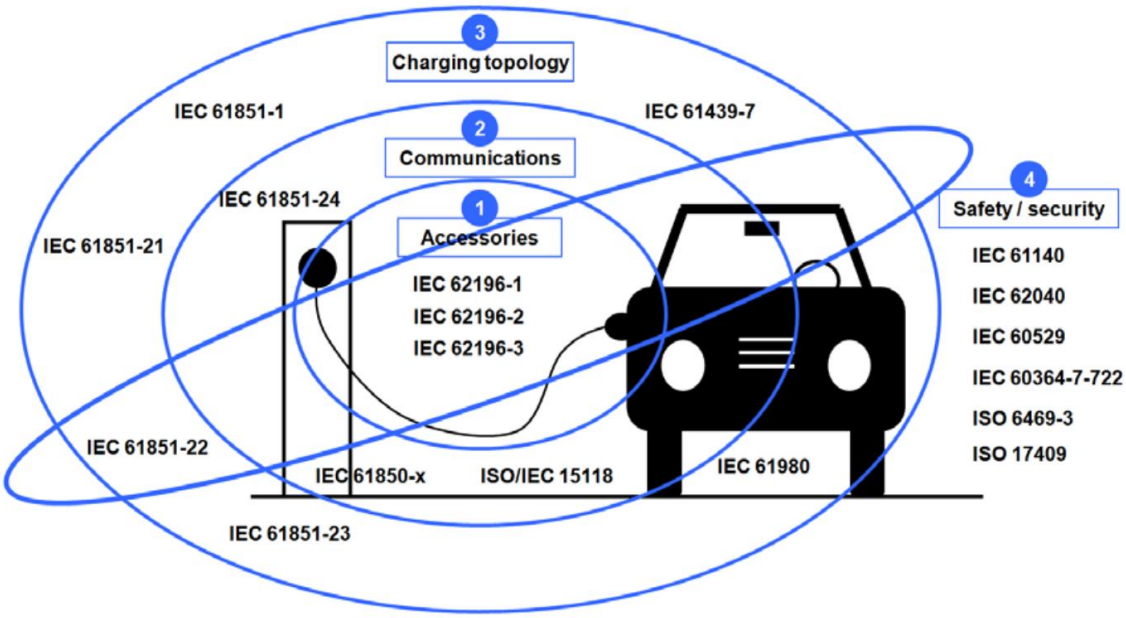


Figure 2. Standardization areas [6]

The list of e-mobility related standards is included in Appendix I.

2.1.3 Charging modes

IEC 61851-1 standard defines different charging modes, the main features of which are specified below.

Mode 1 (Figure 3):

- vehicle can be connected to AC power network via one phase standard socket-outlet
- maximum electricity supply parameters are: 32 A, 250 V,
- cord-set should consist of 3 wired cables (live, neutral and earthing wire),
- mode 1 is planned for slow home charging,
- no energy feedback, no communications.

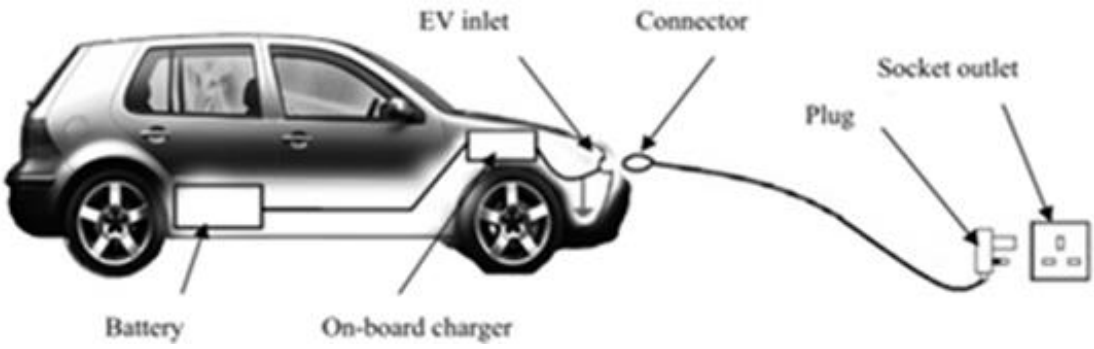


Figure 3. Charging mode 1

Mode 1 utilizes a standard power outlet (socket-outlet) with a simple extension cord, without any safety measures. Although this is what many (private) EV conversions use today, Mode 1 has been outlawed in several countries (RCD protection cannot be guaranteed in some legacy installations).

Mode 2 (Figure 4):

- vehicle can be connected to AC power network (with or without RCD protection) via one or three phase standard socket-outlet,
- maximum electricity supply parameters are: 32 A, 250 V,
- cord-set should consist of in-cable or in-plug protection box (with RCD) with pilot function,
- cord-set should enable communication between in-cable control box and the vehicle,
- mode 2 is planned for slow home or occasional charging.

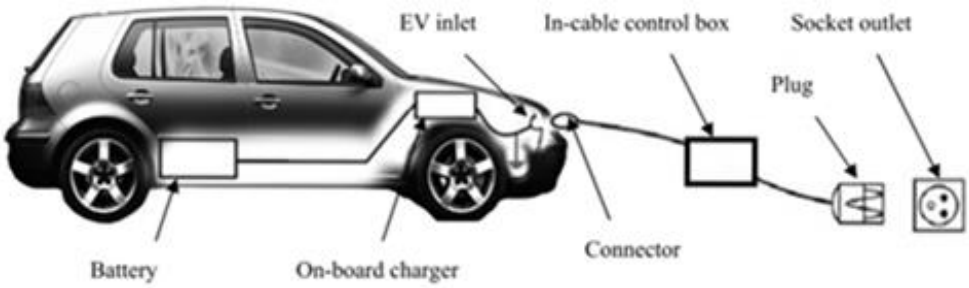


Figure 4. Charging mode 2

Mode 2 cord-set provides a moderate level of safety and is considered as minimum standard for charging an EV [11].

Mode 3 (Figure 5):

- vehicle can be connected to AC power network via dedicated EVSE (EVSE should be permanently connected to the AC network),
- EV to EVSE communication is directly provided by dedicated charging cable (cord-set should consist of additional data wires),
- additional protection via control pilot function should be provided,
- plug interlock permits unsupervised operation, even in a public space (see subchapter 2.3.3.1),
- energy feedback is possible, since communications are bi-directional,
- mode 3 is planned for both home and public charging.

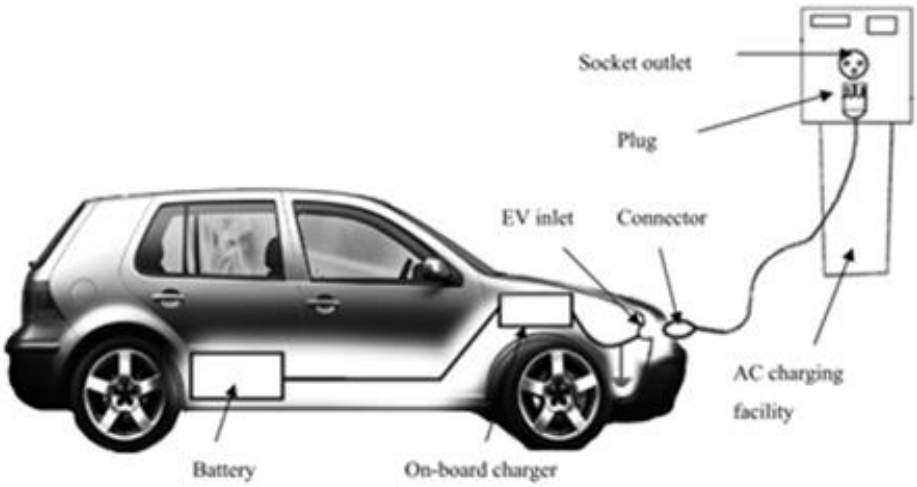


Figure 5. Charging mode 3

Mode 3 and mode 4 are most secure ways of charging. The charging installation is dedicated. Charging access point incorporates monitoring and protection functions. If bi-directional power converters are provided in on-board charger, also V2G options are possible [12].

Mode 4 (Figure 6):

- vehicle can be connected to DC power network via dedicated EVSE
- DC charger is a part of EVSE,
- additional protection via control pilot function is provided,
- data exchange between vehicle and charging equipment is provided, charging equipment is permanently connected to the network,
- mode 4 is intended for public DC charging.

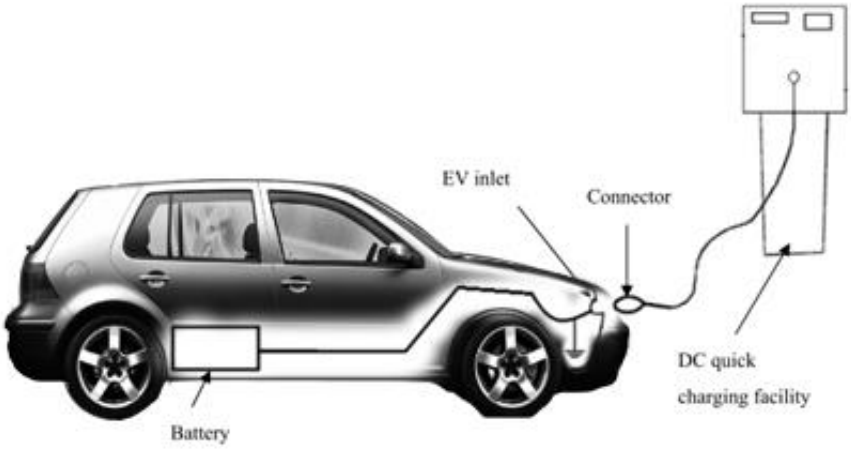


Figure 6. Charging mode 4

Control pilot function

For safety purposes, control pilot (CP) and proximity pilot (PP) functions are essential for charging infrastructure. It is provided by the control conductor in the charging cable assembly. It connects the in-cable control box or the fixed part of the charging facilities with the EV. Its implementation has to meet requirements of IEC 61851. The main control and proximity pilot functions are presented in subchapter 2.5.1.

2.2 EV Technologies

Nowadays, most leading car manufacturers gradually extend their combustion engine assortment with new electric models. Although an access to some products may be limited to particular countries/regions, dozens of EVs are already available and their number is still rising. Among various technologies applied to electric car designs three main approaches can be distinguished:

- Pure Battery Electric Vehicles (BEVs) – vehicle that is propelled by an electric motor and energy is stored in battery. Battery is charged by plugging the car to the electricity network at home or at public charging stations. BEVs do not have any internal combustion engine (ICE) and do not use petroleum.
- Hybrid-Electric Vehicles (HEVs) – vehicles that are powered by a conventional or unconventional fuels combusted in the ICE (Internal Combustion Engine). Additionally, the vehicle drivetrain allows for changing the propulsion to the electric motor that the car is also equipped with. However, the electric energy supplying a motor, stored in the battery, comes only from regenerative braking and ICE (through alternator). While braking, when typically energy is being wasted, the electric motor operates as generator and charges the battery. Electric motor is an auxiliary device and supports the operation of ICE. There is no possibility to charge HEVs through external electricity grid. Charging is an internal issue. HEVs are complex designs because they involve multiple drivetrains that need to be toggled while car is driving – for example changing the propulsion from electric to ICE, or changing the charging target appliance from

ultra-capacitors to battery. Because HEVs use mainly petroleum for vehicles driving and battery charging, they are a good option for long distance transportation.

- Plug-in Hybrid Electric Vehicles (PHEVs) – vehicles that are powered by the conventional or unconventional fuels combusted in the ICE as well as electric energy stored in the battery charged in by external electricity network. While HEVs use only energy from conventional or alternative fuels for propulsion and battery charging, PHEVs can be plugged in to the power system. Therefore, PHEVs can drive only being powered by the electric motor when fully charged. Additional charging is performed during regenerative braking and through ICE, if the battery SOC (State of Charge) is too low. Because PHEVs can run off electricity and petroleum, they are a perfect option for long distance transportation.

Table 2 summarizes the main characteristics of the vehicles using electric energy, including pure battery EVs, hybrid EVs and plug-in EVs.

Table 2. Comparison of BEV, HEV and PHEV [15], [16]

	Pure Battery Electric Vehicle (BEV)	**Hybrid Electric Vehicle (HEV)**	**Plug-in Hybrid Electric Vehicle (PHEV)**
Propulsion	Electric motor	• Electric motor drive • Internal combustion engine	• Electric motor drive • Internal combustion engine
Energy system	• Battery • Ultracapacitor	• Battery • Ultracapacitor • Internal combustion engine generating units	• Battery • Ultracapacitor • Internal combustion engine generating units
Energy source & infrastructure	Electric grid charging facilities	Petroleum stations	• Petroleum stations • Electric grid charging facilities
Characteristics	• Commercially available • High initial investment cost • High battery cost and short life-cycle • Up to 200 km – short range	• Long range • Complex design • Commercially available • Higher cost than conventional car	• Advantages of BEV supported by ICE • Long range (on petroleum) • High initial investment cost • Volvo V60 Plug-in Hybrid is commercially available
Fuel Economy	No liquid fuel	For Honda Civic Hybrid : 38% reduction in fuel cost in the city and 20% reduction on the highway	40-60% reduction in fuel consumption in comparison to the ICE powered vehicles

	Pure Battery Electric Vehicle (BEV)	Hybrid Electric Vehicle (HEV)	Plug-in Hybrid Electric Vehicle (PHEV)
Emissions Reductions	The lowest emissions among any vehicles. However, EV cannot be fully treated as zero-emissions cars because electricity generation leads to pollution. Nevertheless, most categories of emissions are lower.	• Lower emissions than conventional car. • Use of electricity for a part of commuting results in reduction in fuel consumption and in effect reduction in emissions. The benefits are achieved by electricity generation during the most efficient operation of ICE and braking energy regeneration.	• Lower emissions than HEVs and conventional cars. • PHEVs partially operates with electricity only – when fully charged, vehicle produces emissions in the same way as BEV. When battery is discharged, emissions are similar to HEVs.
Flexibility	• Low • Charging only at home and public charging facilities • Due charging is frequently needed	• Medium • Fuelling can be achieved only at gasoline stations • Range is large	• High • Car can be fuelled at the gasoline station and charged at home and public charging facilities • Range thanks to the ICE, is large. Within short distance car can be driven only by electric energy.
Major issues	• Battery + its management • Propulsion performance • Charging facilities	• Management of multiple energy sources and propulsions (drivetrains) • Battery sizing + its management	• Management of multiple energy sources and propulsions (drivetrains) • Battery sizing + its management • Charging facilities • Propulsion performance

COTEVOS considers charging interoperability of EVs that can be connected to public or semi-public EVSEs. Therefore, in the next subchapter an analyses will be performed for plug-able EVs (i.e. BEVs and PHEVs) only. From the interoperability perspective, PHEV should be almost the same as BEV. Differences can be important only for V2G services, when battery capacity is more important. HEV will be neglected in the analyses as they are not connected to the grid – they operate as typical combustion vehicles.

2.2.1 EV components and systems

The main energy source of BEV is battery, which replaces the fuel tank. Other batteries are also installed in other parts of the EV (eg: under seats) in order to provide extension of available travelling distance and ensure electric supply for systems not connected with drivetrain and propulsion. EV's batteries can be charged by on-board chargers utilizing either standard domestic socket-outlet or public EV infrastructure.

Figure 7 presents a general structure of the EV system. The main part of the EV is motor and battery, which together with transmission create a vehicle drivetrain. These main components are supported by a series of auxiliary subsystems. Engine Control Unit, which can be also called "e-motor control", is responsible for operation of the electric motor. BMS – Battery Management System controls a storage operation, including charging and discharging.

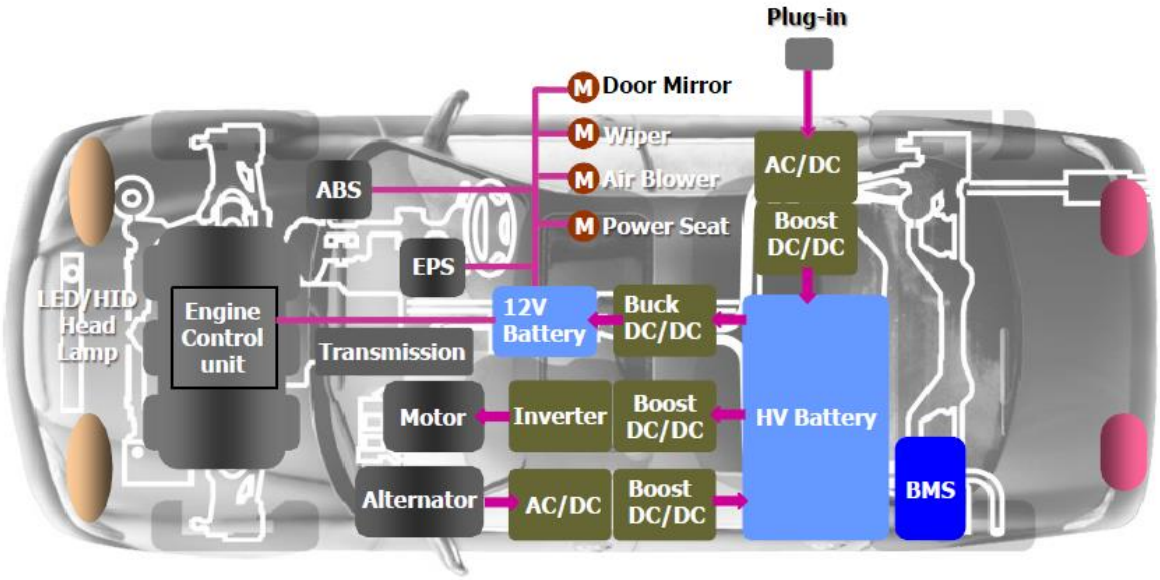


Figure 7. The structure of the EV design [14]

Most EVs are equipped with the on-board chargers, therefore the AC/DC power converter is required. Power converters, being currently in use, are only unidirectional appliances, so they are able to transform energy from AC to DC. This conversion is needed while charging. Meanwhile, the EV system operation requires other transformations in order to supply subsystems. Therefore, several additional converters are needed:

- DC/DC – between internal LV and HV battery in order to charge LV battery,
- DC/DC – between motor and HV battery in order to provide braking energy regeneration,
- AC/DC + DC/DC or single DC/DC – between alternator and HV battery.

Figure 8 presents the structure of EV system. In the Figure, power system is an external energy source and the battery is an internal energy source. Thick arrows show an energy flow, while thin arrows represent communication and control signals. Double

lines stand for a mechanical link such as between an electric motor, transmission and wheels.

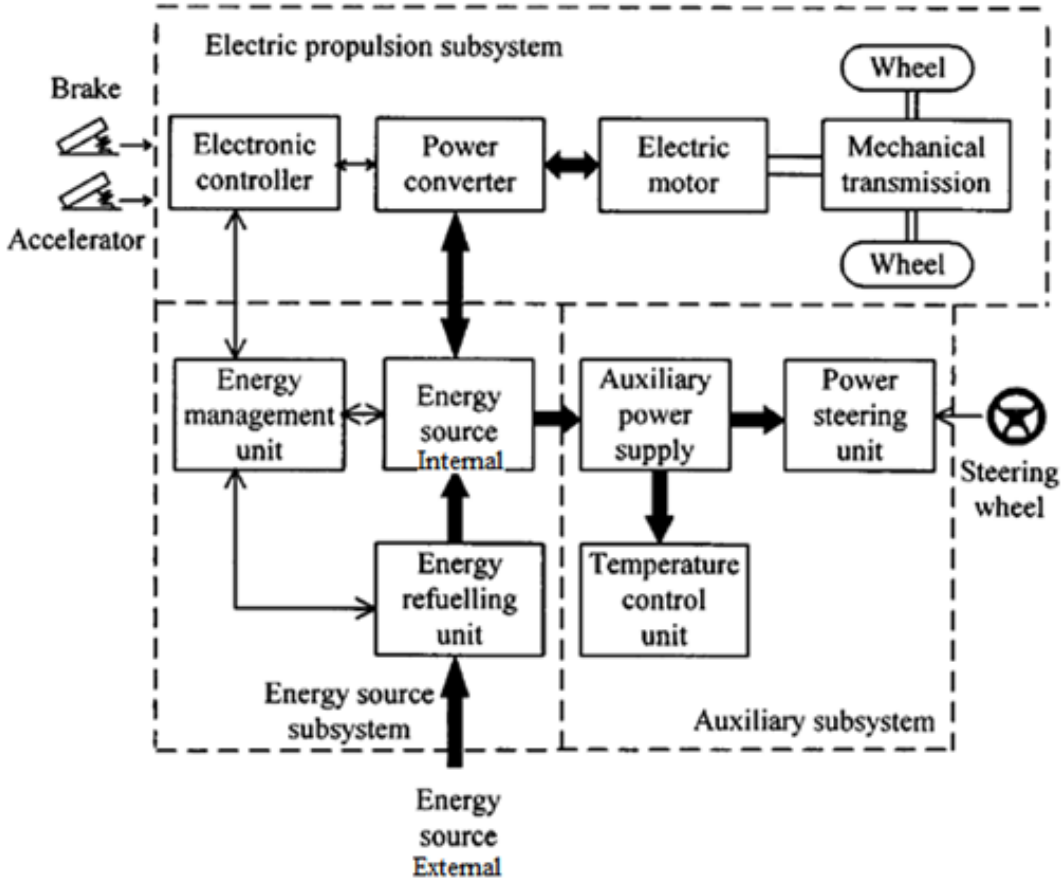


Figure 8. General EV system structure [15]

EV system consists of three main subsystems:

- Electric propulsion subsystem,
- Energy source subsystem,
- Auxiliary subsystem.

An electric propulsion subsystem is fully internal, which means that it does not affect interoperability. Technical solutions used are the issue for vehicles manufacturer. EV user does not interfere with this subsystem.

An energy source subsystem includes battery (internal energy source) and systems that allow for its charging and discharging: energy management unit/battery management system, refuelling system, charger on-board (not presented in the figure) etc. Major subsystem components are internal and similarly to the electric propulsion subsystem, the EV user does not affect their operation with one exception: connection to the power system. This is performed by the vehicle power inlet and the EVSE connector. The car manufacturer's responsibility is to provide an interoperable inlet.

An auxiliary subsystem is not fully described in the figure. In fact, all other systems providing additional functionalities can be included into this category i.e. human

management interface. Most interoperability-involving issues are related to the last subsystem – auxiliary. It includes peripheral equipment that EV user deploys during everyday driving, charging etc.

As it was previously said, the EV system structure, as described above, refers mainly to the BEV. PHEVs will be in a manner similar to EVs in their structure but they will consist of additional systems for drivetrain – at least two switching propulsion systems: electric motor and internal combustion engine. The energy source subsystem will be also extended by ultracapacitors, for instance. Although PHEVs are much more complex and difficult to design by manufacturers, the interoperability issues will be almost the same as in case of BEVs.

2.2.1.1 **Charger**

Next to the battery, the charger is one of the most important parts of the energy source subsystem. It in fact provides all energy necessary for propulsion and for the auxiliary devices. The charger allows the battery to be charged from the electricity grid. From the technological perspective, the charger is AC/DC power electronic inverter. While charging its operation is fully controlled or supported by the BMS. The AC voltage is transformed into DC voltage that suits the battery parameters. The charger operation is constrained by the safety requirements of the battery used in the EV.

There are two main approaches to the charger design – built-in into EV (on-board) or external (off-board). On-board charger is an inseparable subsystem of the EV. It can operate as one-phase and three-phase charger. One-phase chargers are most common solutions as compared to more expensive three-phase designs. They are mostly dedicated to slow charging at home, whereas three-phase chargers are designed for fast AC charging. DC fast charging requires the deployment of high power off-board charger. It is a part of external charging supply equipment and is connecting with EV for charging. The main advantage of off-board charger is that it does not affect the EV price, as the charger is not a part of vehicle.

The charger nominal power depends on battery capacity.

Currently, the market offers only one-directional chargers. The development of bi-directional chargers is not a technical problem but such a charger is simply too expensive without a proper business case allowing the investment to be earned back. For V2G applications bi-directional chargers are required.

2.2.1.2 **Batteries**

Battery is the EV energy source subsystem. Since it is one of the most important components of BEV it may require special care and handling. For instance, in case of DC fast charging, EV's BMS system and charging station should establish the bi-directional communication to exchange information such as battery charging pattern, State of Charge (SOC), temperature, etc. The following subchapter presents an overview of the EV batteries in three main aspects:

- Type of battery,
- Charging pattern for lithium-ion battery,
- Battery ageing.

Type of battery

Currently, batteries are most problematic components of the EV systems. Main issues involve their weight, price, capacity, lifetime, electrical parameters and dimensions. However, EV batteries market segment is rapidly developing, as all manufacturers and e-mobility stakeholders are aware that batteries are crucial for the sector further development. Already today we can identify the following battery technologies [17]:

- Nickel-Metal Hydride batteries (NiHM),
- Sodium-Nickel Chloride batteries (NaNiCl),
- Lithium-ion batteries (Li-Ion),
- Lithium-Metal Polymer batteries (LMP),
- Zinc-Air batteries (Zinc-air),
- Lithium-Sulfur batteries (Li-Sulfur),
- Lithium-Metal-Air batteries (Li-Oxygen),
- Lithium-Air batteries (Li-air).

The above battery technologies are also presented in Figure 9 with an indication to the specific power and energy. These parameters vary depending on the application. EVs require highest possible specific energy, while high specific power is needed in case of fast charging.

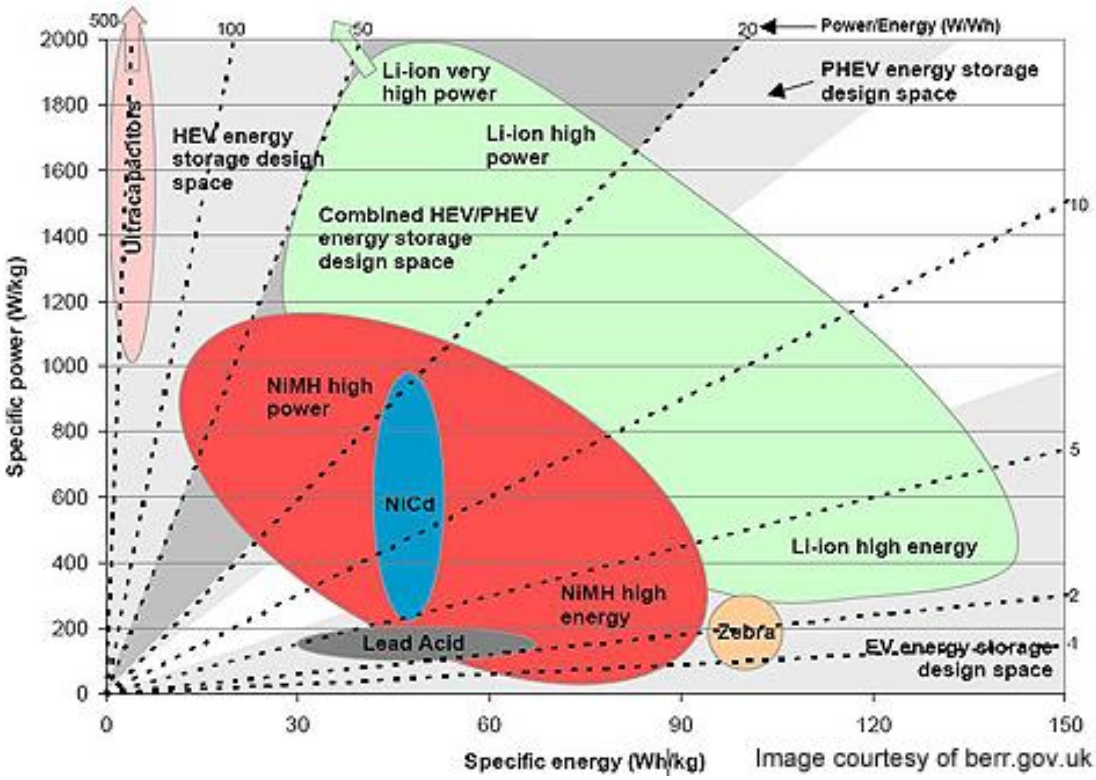


Figure 9. Energy and power of different types of batteries [105]

The most popular battery technology for EV is Lithium-ion (Figure 10) [105]. This battery type can be designed using various cathode and anode materials such as lithium titanate, lithium-cobalt or lithium-iron-phosphorus. Li-ion promises a high energy density, lifetime and charging cycles. Li-ion batteries are characterized with energy density of 130 Wh/kg, cell voltage of 3,7V and expected number of cycles – 3000 assuming that the Depth of Discharge (DoD) is at 80%.The highest practical energy density can be achieved within cobalt cathode (120-180 Wh/kg). According to Figure 10 a promising technology according is Li-air battery. However, it requires much effort in R&D.

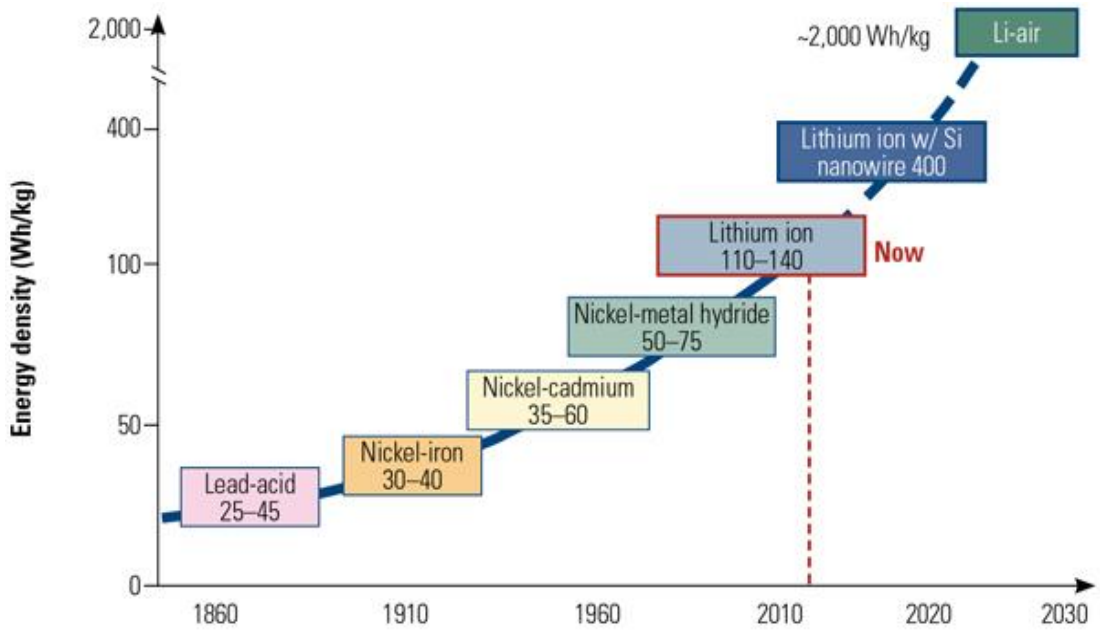


Figure 10. Battery technologies and energy density [17]

Charging pattern for lithium-ion battery

The lithium-ion battery does not accept overcharging (which is in fact a constraint on all traditional batteries). For this reason, manufacturers of Li-ion cells emphasize that a correct charging process should be followed. The cells are to be charged up to 4,2 V/cell with a tolerance of +/- 50 mV/cell. Higher voltages could increase capacity but would reduce battery lifetime.

Figure 11 describes a charging process for a single battery cell. The highest current value occurs during the first hour of charging. Subsequently, the current value decreases to zero amps approximately in the second charging hour. At the beginning, the charge level goes up linearly. Later, an increase in SOC is nonlinear. We can also notice a relatively significant voltage stroke when charging begins and almost a constant value during the remaining time of charging.

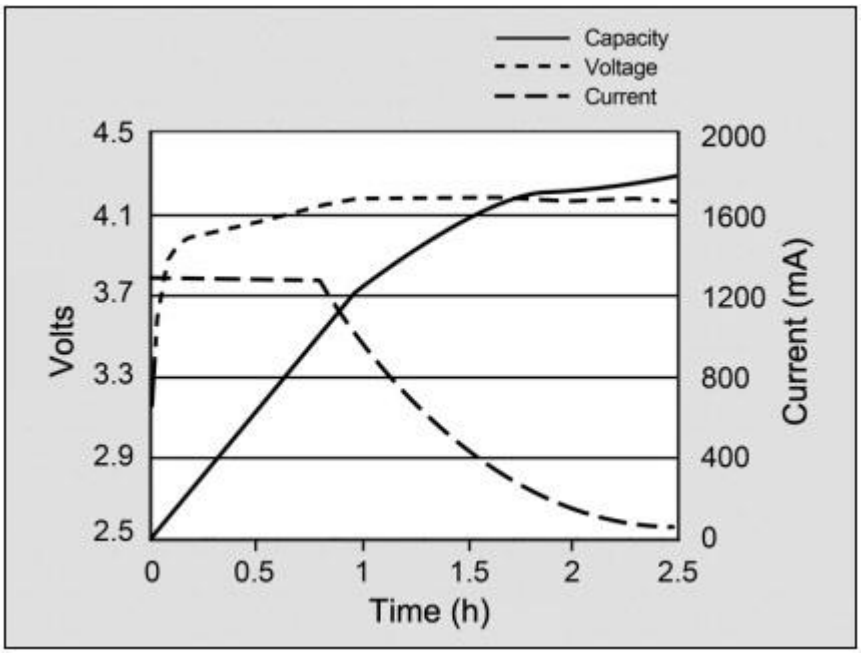


Figure 11. Charging pattern of lithium-ion battery [18]

Battery ageing

Battery ageing depends on several factors. The main drivers which imply battery lifetime are: charging speed (charging current), charging and discharging levels (deep discharging has highly negative impact on battery), battery age and operation temperature. Car and batteries manufacturers have arranged goals for all these factors, but they are not fully clear. For battery age, the goal is approximately fifteen years. For operation temperature requirement cannot be stated as general. It depends on battery chemistry. Higher and lower temperatures degrade battery lifetime.

The next factor affecting battery ageing is charging and discharging level. In this point two elements can be distinguished – charging/discharging current and level when discharging ends. Charging pattern depends on EV user. The best for battery is slow charging and discharging only to 30-40% of available nominal capacity.

Figure 12 presents a typical battery degradation. It depicts how the battery Depth of Discharge (DoD) affects expected charging cycles. Important is that assuming only 80% DoD, number of cycles is about 2000, while for <10% DoD it reaches hundreds thousands.

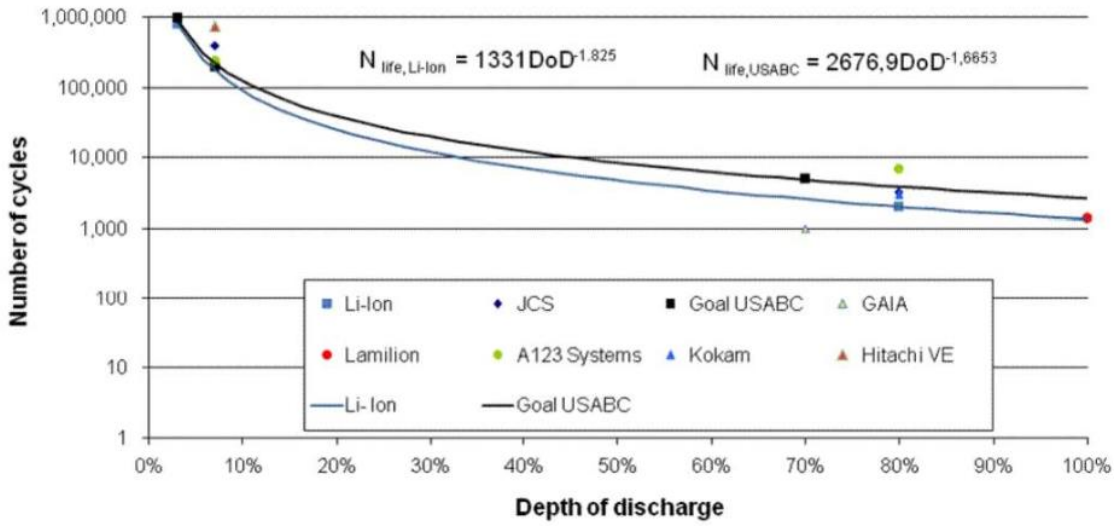


Figure 12. Battery cycle life dependent on DoD and battery degradation [105]

Battery development is crucial for further e-mobility development. The most urgent issues includes increasing energy storage capacity, allow for high current charging and extended lifetime.

Battery costs

Costs of the batteries are much less important for interoperability, however have a significant impact on every business model for e-mobility. Costs are especially important for services built on the EV and its energy storage (such as V2G), as the market model and prices shall include sensitive issue as the battery lifetime is.

For costs description two main aspects can be distinguished: investment cost and degradation cost. For every service important is degradation cost as it describes 1 kWh discharged with the assumed DoD. Degradation cost includes investment cost, which nowadays vary from 180-380 €/kWh, with the long-term projections at the level of 65-80 €/kWh [105]. Definition of degradation cost is difficult, due to complexity of the battery operation. As it was stated before, many elements influence battery efficiency and lifetime, therefore degradation cost must be described with the battery simplified model and several assumptions made. The figure below depicts the curve for the degradation cost depending on the DoD and investment cost.

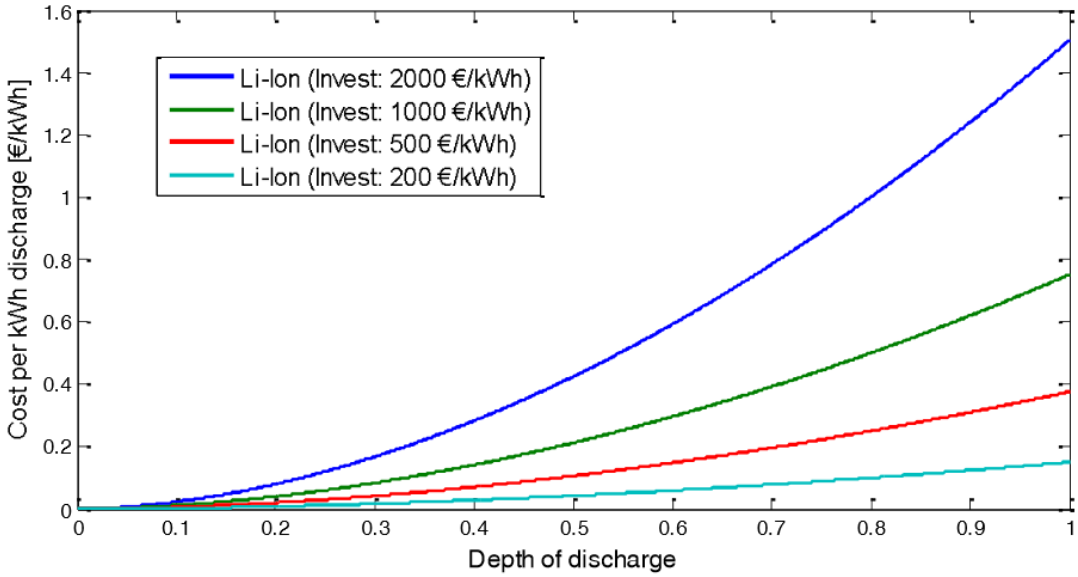


Figure 13. Costs per kWh depending on the DoD for different investment costs [105]

2.2.1.3 **Battery Management System**

Battery Management System (BMS) handles operation of the EV battery. It controls charging and discharging process together with charger (see Subchapter 2.2.1.1). Control strategy is in most cases arranged for extending battery lifetime. BMS prevents also from deep discharge and wrong charging parameters. The BMS tasks can be summarized as:

- Controlling / supporting charging and discharging process,
- Protecting battery from operating outside the acceptable range,
- Monitoring battery SOC and battery condition (Battery monitoring system includes: voltage control, temperature, SOC, state of health, current and coolant flow),
- Reporting data.

Figure 14 presents an example BMS system composition. It consists of three main subsystems: centralized, distributed and modular. Centralized part is a single controller connected to the battery cells (wire connection). Distributed components involves BMS board, which each cell is equipped with. Modular subsystem involves a few controllers which handles operation of a certain number of cells.

BMS needs to send required data to other devices in EV system. Main measures used for this purpose includes:

- CAN BUS,
- Direct wiring,
- DC-BUS,
- Wireless communication.

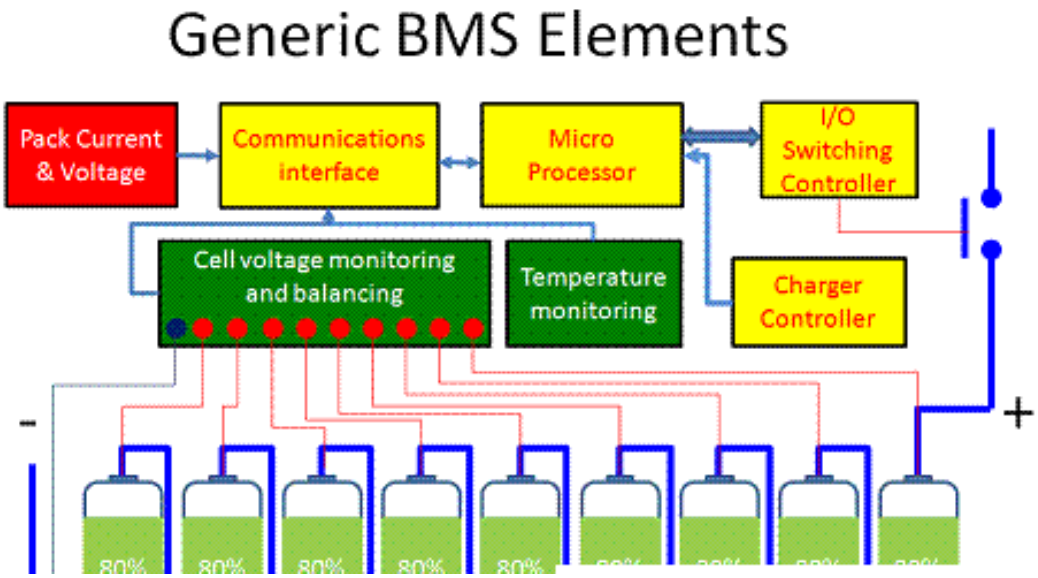


Figure 14. Battery Management System

BMS has very limited impact on EV system interoperability in case of charging mode 1, 2 and 3. Then, BMS is crucial for energy source subsystem but is fully internal. During everyday use, EV user does not influence operation of BMS – it is independent.

In case of fast DC charging – mode 4, interoperability issue occurs as the DC charger (built in charging station – EVSE side) exchange information with the BMS (EV-side) in accordance with CHAdeMO or ISO 15118 (see DC charging description in subchapter 2.3.3.1).

2.2.1.4 **Human Machine Interface**

Human Machine Interface (HMI) lays at the software layer of the EV systems and is a part of auxiliary EV subsystem. It is an application that presents information for the EV driver, such as EV system current state, battery SOC or operational instructions. It is also a measure for information exchange and mutual communication between electromechanical system and the user. Information is displayed in a graphical form. HMI allows the user for completing setting through touchable screens.

Figure 15 presents an exemplary sight of Human Machine Interface for EV.

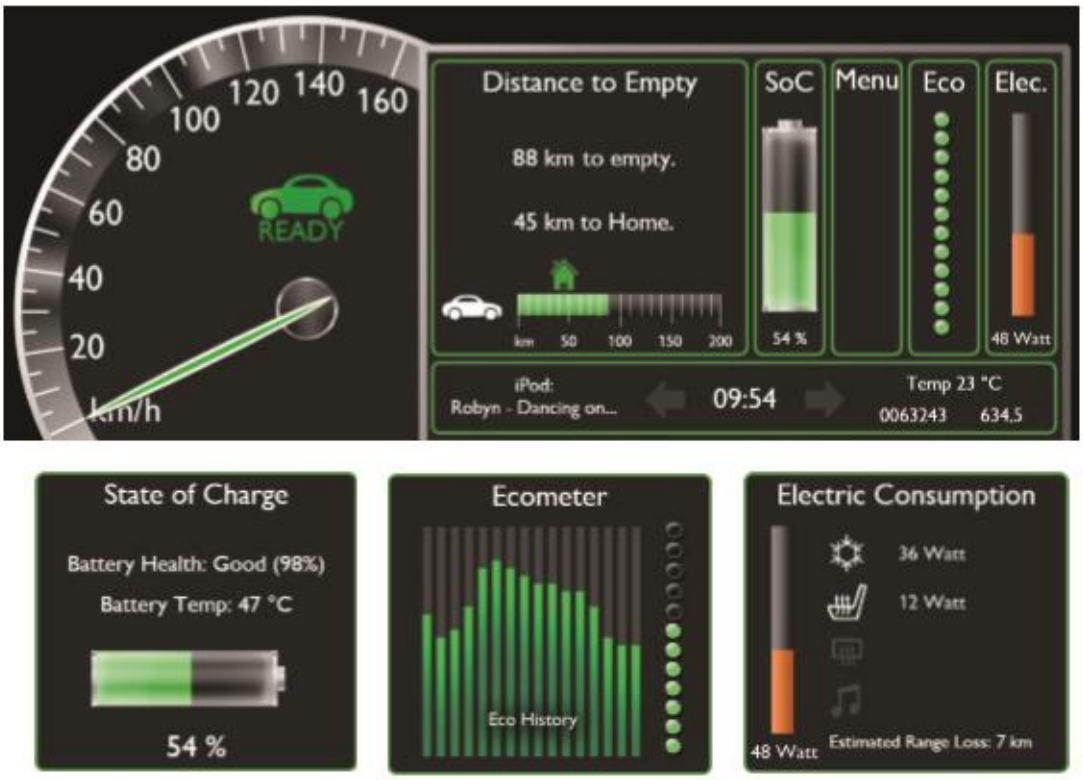


Figure 15. Human Machine Interface for Electric Vehicle [20]

Human Machine Interface may provide EV user the following information:

- Actual remaining EV range,
- Battery SOC,
- Current electric energy consumption,
- Ecometer – indication of the efficient vehicle use,
- EV state,
- Battery state.

Additionally, HMI can be equipped with features and functionalities not directly connected with EV operation such as: GPS navigation, external communication (Bluetooth, NFC etc), media connection, etc.

Above examples of HMI functionalities does not close the list. Direct design of HMI depends on manufacturers. A relevant remark that can be made about the HMI is that with the (PH)EVs currently on the market it is sometimes possible to schedule a charging session manually. For supporting dynamic (market based) and Demand-Side-Response programs a more advanced HMI will be required.

2.2.1.5 **Range extender**

Range extender is an auxiliary power unit built in or externally included in BEVs or PHEVs in order to increase their electric range. There are three technologies of range extender:

- An additional Internal Combustion Engine (ICE). ICE does not provide direct power for vehicle driving only drives generator which charge the battery. Operation of ICE is independent on EV operation.
- Piston engine with new designs from scratch for fairly constant load in series hybrids.
- Microturbine and fuel cells that operates at constant load.

The range-extender which additionally charge the EV battery during a journey provides an important input for increasing the market penetration and customer acceptance of EVs. This system does not have direct impact on interoperability issues however is relieving the so-called “range anxiety”. Since in some locations charging infrastructure might be limited, the additional range and thus the greater choice of charging stations helps to mitigate the fear that at the charging destination it will be impossible to charge vehicle, e.g. because connector/inlet compatibility or of RFID cards reader failure.

2.2.2 Market available products

As nowadays e-mobility is rapidly developing, EV manufacturers try to provide the wide range of various EV designs. Table 3. presents the pure battery electric vehicles – BEVs and hybrids – PHEVs. Columns describe some important parameters of the cars including motor drive power, the battery type, voltage and capacity and vehicles range (guaranteed by the manufacturers).

Table 3. The list of vehicles with electric drive

Vehicle manufactures	Model	BEV	PHEV	Power [kW]	Battery type	EV range [km]	Battery voltage [V]	Battery capacity [kWh]
Mitsubishi	i-MiEV 2014	X		47	Li	160	330	16
Honda	FIT – EV Japonia	X		X	Li	113	x	20
Kia	Naimo	X		80	Li-Poly	X	330	16
Nissan	LEAF	X		80	Li	175	X	24
Mercedes	B ELECTRIC DRIVE	X		130	Li	X	330	16
	SLS Coupe Electric	X		552	Li	X	400	60
	4WD Full Electric	X		200	Li	X	355	56
	Sprinter E-Cell	X		100	Li	X	x	35,2
Volkswagen	e-up	X		40	Li	X	374	18,7
Opel/Vauxhall	Ampera		X	111	Li	80/500	X	16
Smart	Fourjoy	X		40	Li	X	x	17,6

Vehicle manufactures	Model	BEV	PHEV	Power [kW]	Battery type	EV range [km]	Battery voltage [V]	Battery capacity [kWh]
	Ed	X		30	Li	135	330	17,6
Toyota	iQ-EV	X		40	Li	X	330	16
	Prius Plug-In		X	68	Li	18/870	X	4,4
	RAV4 –EV	X		115	Li	X	240	41,8
Renault	Zoe	X		60	Li	160	400	22
	Kangoo Maxi Z.E.	X		44	Li	170	398	22
	Twizy	X		15	Li	100	X	7
	Fluence Z.E.	X		70	Li	161	398	22
Fiat	500e	X		15	Li	130	X	22
Citroen	Berlingo Electric	X		42	Na-NiCl	X	X	23,5
	C-Zero	X		49	Li	130	330	16
Mazda	Demio EV	X		75	Li	X	346	20
Audi	A2 Concept	X		60	Li	X	X	31
	Urban Concept	X		15	Li	X	X	7,1
Peugeot	Partner Electric	X		49	Li	X	300	22,5
	iOn	X		35	Li	130	330	16
Brusa	Spyder	X		95	Li-Poly	X	X	16
Infiniti	LE Concept	X		100	Li	X	X	24
Chevrolet	Spark EV	X		100	Li	X	X	21
	Volt		X	111	Li	56/480	X	16
e-Wolf	Alpha 1 SRF	X		140	Li	X	520	41,5
Rolls Royce	Phanton 103 EX	X		290	Li	X	338	71
Byd	BYD e6-Eco	X		115	Li	330	X	60
Ford	Focus Electric	X		100	Li	160	X	23
	Connect EV	X		50	Li	160	X	21
Volvo	C30 BEV	X		82	Li	150	X	24
Romet	4e	X		X	PbO_2	X	330	16
Skoda	Octavia Green E Line	X		85	Li	140	X	26,5
Venturi	America	X		220	Li-Poly	X	X	54

Vehicle manufactures	Model	BEV	PHEV	Power [kW]	Battery type	EV range [km]	Battery voltage [V]	Battery capacity [kWh]
Saab	9-3 ZE	X		135	Li	200	X	35,5
ERA	Electric RaceAbout	X		282	Li	X	415	32
Re-Volt	Re-Volt	X		X	Li-Poly	X	133	7
TESLA	Model S	X		225	Li	390	X	60
				270	Li	490	X	85
	Model S performance	X		310	Li	490	X	85
Think	City	X		34	Na	160	X	24
Mini (BMW)	MINI E	X		150	Li	195	X	35
Coda	EV	X		100	Li	193	X	34
BMW	i3	X		125	Li	190	X	18,8
	I8/I8 Spider		X	96	Li	35/500	X	7,1

Legend: Battery type: Li – based on lithium, PbO2 – lead acid, Na – based on sodium

2.2.3 Time of charging

At present, charging time of EVs spans from less than 30 minutes to over 10 hours (Table 4) and depends on:

- supplying grid parameters (e.g. one/three phase, nominal fuse current, smart grid services, etc.),
- maximum power enabled in particular connector/inlet standard (see subchapter 2.3.2.1),
- charging mode,
- the type of battery, its capacity, charging profile and how it is depleted,
- power of on-board/off-board charger.

Although in some situations (e.g. during travel) there is a need for fast charging options, due to the ageing issues (see subchapter 2.2.1.2), it is advisable to charge batteries with a possibly low current. The charging speed might be additionally limited by other factors such as: EVSE management system (if more EVs are simultaneously connected to the same charging station), predefined charging schedule, V2G services, etc.

2.3 State of the art of EVSE

2.3.1 Current situation in EVSE development

At present one of the most substantial EVs disadvantages is related to their relatively short range that usually does not exceed 150 km on fully charged batteries (see Table 3 in subchapter 2.2.2). A short range of EVs may be more tangible taking into

account the fact that it depends (similarly as in combustion vehicles) on factors such as driver's habits and road conditions.

Another important issue for EVs development is the time of charging (see Table 4). Currently it is not feasible to put the 20-25 kWh of electric energy needed to travel 150 km into the battery in the time comparable with refuelling combustion engine car. While petrol or diesel refuelling is the matter of minutes, the time required to charge depleted batteries can range from less than 30 minutes to several hours (it depends on the size and type of batteries and the type of charging equipment used). On the other hand the time of charging itself is not the only issue. Providing electrical distribution facilities to allow users to consume 20 -25 kWh from the electricity grid in single minutes is neither practical, nor economical and even if it was, no EV battery could accept such amount of energy at this rate.

Table 4. Estimated time to charge up a depleted 24 kWh battery using different charging levels [23]

Charging time	Power Supplied	Voltage	Maximum Current	Mode	Speed
10.4 hours	2.3kW	230 V AC	10 A	2, 3	SLOW
8.3 hours	3kW	230 V AC	13 A	2, 3	SLOW
6.5 hours	3.7kW	230 V AC	16 A	2, 3	SLOW
3.2 hours	7.4kW	230 / 400 V AC	32 A	3	AC Fast
1.6 hours	14.5kW	400 V AC	63 A	3	AC Fast
1.04 hours	23kW	400 V AC	100 A	3	AC Fast
29 minutes	50kW	400-500 V DC	100 – 400 A	4	DC Fast
15 minutes	100kW	400-500 V DC	100 – 400 A	4	DC Fast

Furthermore, uneven development of charging infrastructure around EU countries and worldwide is another drawback affecting EVs market growth [24].

There are no single means to mitigate these deficiencies. Solutions do not just involve the development of chargers, they involve and require the design and roll out of a network of public and private charging stations with associated e-mobility services and improvements of the electricity grid to carry the increased load. As it has been stated in the previous subchapter most of market available BEVs and PHEVs are equipped with on-board AC chargers. Such vehicles can be connected to regular domestic/industry standard socket-outlets via a cord-set, which is usually provided by a car manufacturer. In particular, it is convenient for commuting car owners who have an access to private parking space and individual power supply, which involves no additional expenses for charging equipment. In fact, the EV might be treated as another household load. Consequently, slow overnight charging is nowadays the most popular scenario.

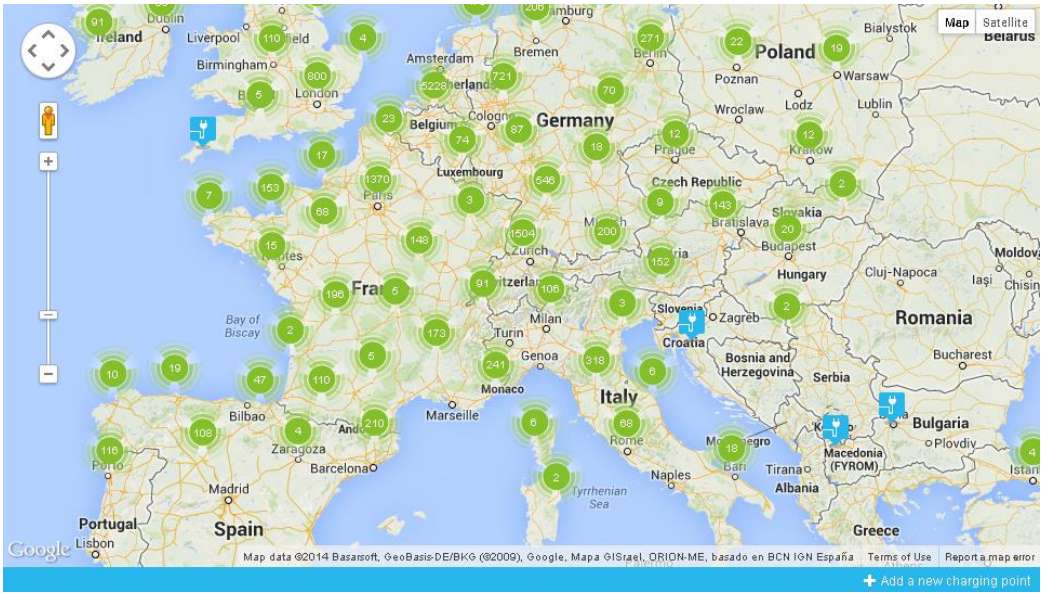


Figure 16. Number of public charging points available from website: www.chargemap.com

Although slow charging might be sufficient for commuting private EV owners, it is probably not for others, such as corporate fleet operators, taxis, transport couriers etc., who often require publicly accessible charging infrastructure available 24 hours per 7 days. Additionally, regular commercial EVs require bigger batteries which in turn need higher power charging stations to achieve reasonable charging times.

Regardless whether the EV owner is private or commercial, the vehicle may be used a long way from its base (e.g. for a trip), further than it results from a single battery charge range. In such a case low power charging should be treated as an emergency option. Instead, a high power DC charging is recommended. This however requires publicly available DC charging infrastructure.

For commercial vehicles there are also other charging options. If the vehicle follows prescribed routes within a limited range, it is possible to plan an access to adequate charging infrastructure. In case the destination is in the range of vehicle, DC charging is possible saving weight and space on the vehicle. The other option may utilize battery swap functionality. Each vehicle may have the couple of removable batteries packs with one being charged while the other is in use. The vehicle depletes the battery during each journey and picks up a fully charged battery at the terminal base.

The following subchapter addresses the issues associated with providing different means of charging necessary to support the growing population of EVs.

2.3.2 Charging equipment

The EV batteries can be charged with either AC or DC voltage (see Figure 17). The on-board charger enables AC charging whereas DC charging requires off-board charger.

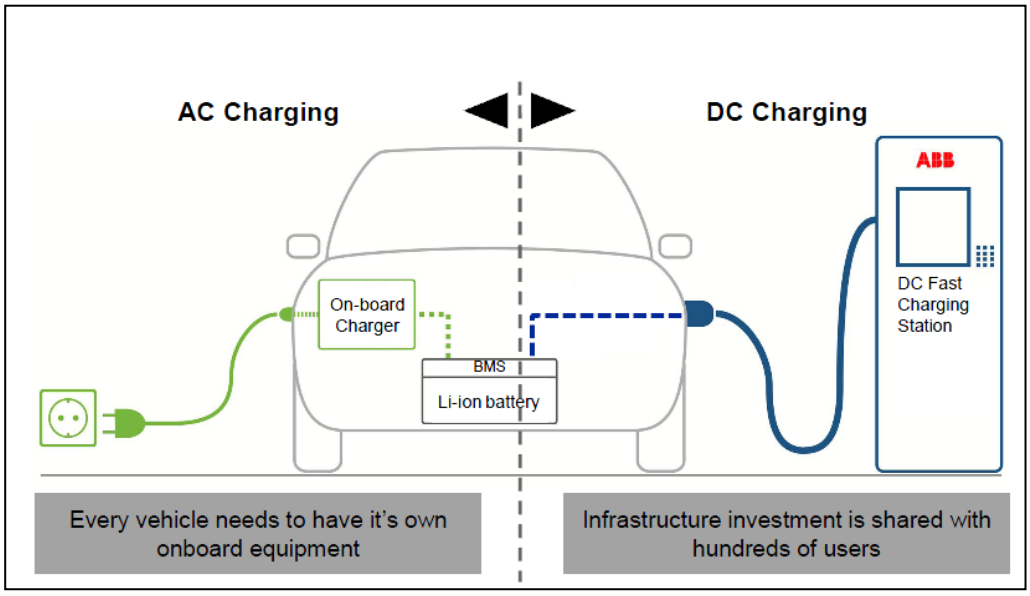


Figure 17. AC and DC charging [21]

2.3.2.1 **Connectors**

The following subchapter deals with the specification of EV inlets and cord-set (cable) connectors.

In Europe all inlets and connectors should meet the IEC 62196-X standards. The other existing standards are: SAE J1772 (North America) and CHAdeMO (Japan). Table 5 contains a list of currently most popular inlets and connectors.

Type 1 is one of the oldest standards for connector/inlet defined by IEC 62196-2 and in SAE-J1772. The technology allows for single-phase AC slow charging. Maximal charging power is up to 7,2 kW.

Type 2 is defined by IEC 62196-2 standard as the AC three-phase equivalent of type 1 connector. As it is possible to use three phases, charging power can be up to 43 kW.

Type 3 is a hybrid solution for both single- and three-phase charging but connector parameters are different. Maximal charging power is 22 kW.

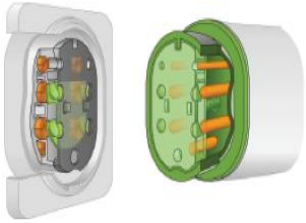
CHAdeMO is defined by IEC 62196-1 standard and is commonly used in Asian cars. Unlike in previous connectors, the Chademo is used for DC charging under operational voltage 500 V and currents up to 120 A. Charging power is relatively high - up to 60 kW.

Combo is the European equivalent of DC connectors. Technical issues are defined by the same standard as for types 1-3 (IEC 62196-2. Nominal voltage is 500 V DC and current up to 200 A.

Combo2 is defined by IEC 62196-3 standard and it seems to be a dominating solution in the nearest future. Combo2's main advantage is the availability of charging on

three voltage levels: 120 V AC, 240 V AC and 500 V DC - the inlet is compatible with the Combo2 - DC and type 2 - AC connector.

Table 5. List, standards and differences between EV connectors and inlets

Connector / Inlet	Illustration	Standard	Max voltage	Max current
Type 1		SAE J1772-2009 IEC 62196-2	250V AC Single-phase	32A single-phase
Type 2		IEC 62196-2	500V AC three-phase 250V AC Single-phase	63A three-phase 70A single-phase
Type 3		IEC 62196-2	500V AC three-phase 250V AC single-phase	16/32 A single-phase 32A three-phase
Chademo		IEC 62196-1	500V DC	120A DC
Combo		IEC 62196-2	500V DC	200A DC
Combo2		IEC 62196-3	500V DC 120V AC 240V AC	200A DC 16A AC 80A AC

It is noticeable, that although the construction of inlets and connectors does not allow to mix different solutions, some manufacturers already offers dedicated adapters. Such equipment enables to connect the type 1 inlets with type 2 connectors (type 1 and type 2 share the same standard for control signal).

In 2013 the European Commission unveiled a plan to unify the vehicle inlet standards. According to the plan only one standard should remain in Europe – Combo2. The proposed solution provides background for unification of AC and DC charging powers and enables compatibility among the systems. This EC decision is supported by the European Automobile Manufacturers Association – ACEA, see Chapter 0.

Simultaneously, it seems that the market itself has already chosen Combo2 as a target system and it will be most widely used inlet/connector in 2014 Figure 18.

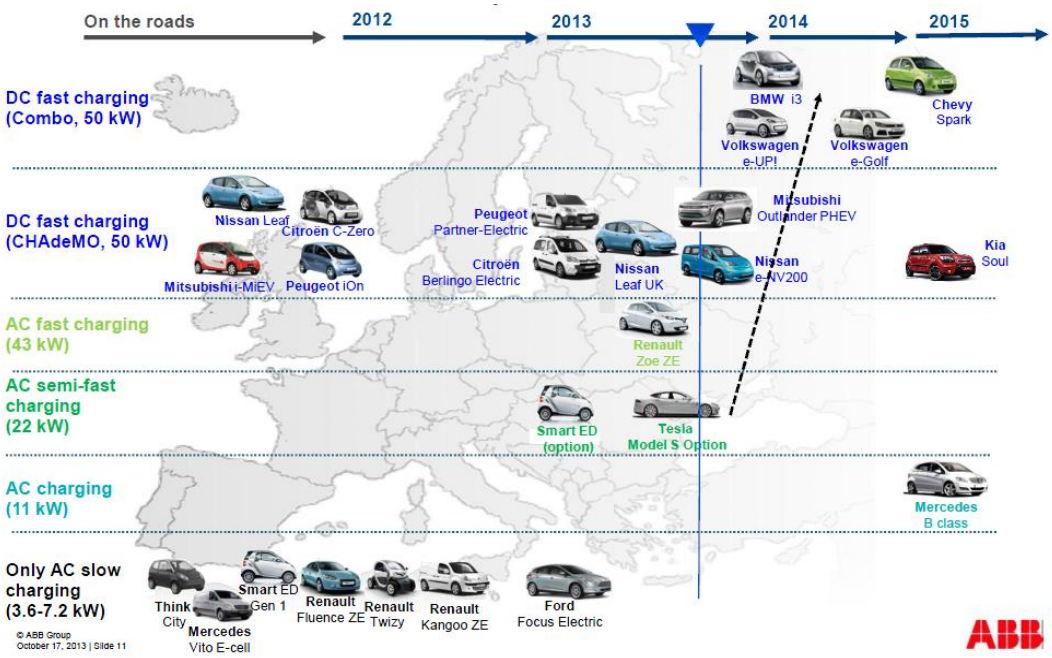


Figure 18. Charging options for market available EVs [21]

2.3.3 Charging technologies

Considering the known measures of delivering energy to EVs and making the analysis of market available products, one can identify charging technologies that are already adopted or are expected to be adopted in near future:

- wiring (conductive) charging
  - AC charging,
  - DC charging,
- wireless (inductive) charging,
- battery swap.

2.3.3.1 **Wiring charging**

Nowadays the conductive charging is most common solution. The charging station might provide either AC voltage or DC voltage (some products offer both options). If AC is used for charging, the energy is supplied directly from the existing low-voltage network to the on-board AC/DC converter in the vehicle (see subchapter 2.2.1). In case of DC charging, the AC/DC converter is located within the charging station.

Though in Europe all available conductive charging stations should comply with IEC 61851 Standard, there are possible significant differences between particular products that arise from:

- anticipated charging station environment (home, public, indoor, outdoor, etc.),
- type of voltage provided (AC or DC),
- implemented charging modes (in accordance with IEC 61851 and vehicle connectors (IEC 62196),
- billing services,
- communication and e-mobility services,
- maintenance options e.g. remote service and driver assistance,
- safety precautions, etc.

Examples of different types of charging states are presented later in this subchapter.

Taking into account communication functionalities, one can identify two types of charging architecture:

- autonomous charging stations,
- clusters of charging stations.

Although both can be equipped with advanced options, the latter might require cluster management systems securing power management and enabling advanced ancillary services such as V2G.

AC charging

If EV charging is provided in compliance with mode 1 or 2 (IEC 61851) the EVSE equipment is limited to a cord-set (usually supplied by the vehicle manufacturer) that can be connected to the existing AC power network (Figure 19). Charging can be carried out from a regular domestic/industrial socket-outlet and is suitable mainly for private, domestic installations and does not need authentication and billing. Since Mode 1 and Mode 2 offer limited safety and communication options, this equipment should be used occasionally, during initial/transitory EVs implementation phase (and mainly in private locations).

For new installations and all public infrastructure Mode 3 is being dedicated. It incorporates functionalities required to improve safety and communication abilities.

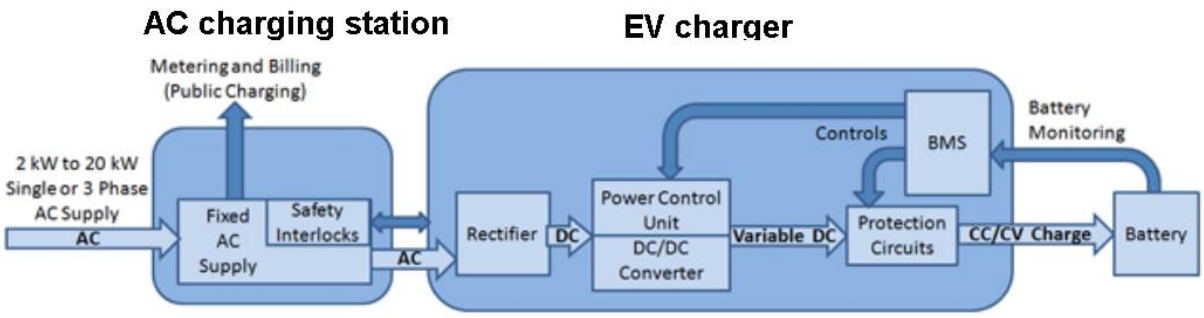


Figure 19. Key components of the AC charging station and EV charger

For that purpose the standardized Type 2 [25] connector is equipped with both PP and CP signal contacts assuring functions such as confirmation whether the connector is correctly inserted in the inlet or which current may be used for charging (see subchapter 2.5.1). An interlocking mechanism prevents withdrawal of the connector from inlet while energized or prior to completion of all necessary transactions, such as payment. It can be implemented both on the vehicle and on the charging station, ensuring higher safety of the system, Figure 20.

Figure 20. Connector interlocking equipment (Phoenix connector – left picture, Mennekes inlet with locking actuator – right picture).

Every charging station that is compliant with Mode 3 (including those for domestic/private charging) should consist of the following components [26] (Figure 21):

- Protective equipment like RCD (Residual Current Device) and MCB (Miniature Circuit Breaker),
- Contactor preventing (isolating) charging station socket outlet (or the connector itself if the cable is fixed to the charging station) from being energized while not connected to EV. It stays deactivated until communication is established with the vehicle and until the earthed conductor connection is checked.
- The charging controller enabling and controlling charging in accordance with the IEC 61851 standard. It communicates with the electric vehicle, identifies the charging cable, and controls and monitors the connector (continuous protective earth checking is required) and the plug interlock. The charging controller thus ensures safety for the charging operation.

- Actuator as part of the charging socket for interlocking and/or releasing the plug in the socket

In AC charging stations, before the charging process starts, the communication with the EV must be established (via the CP cables). Several parameters are transmitted and adapted. Charging should not start until all safety prompts meet the specifications and until the maximum admissible charging current is not confirmed. The following test steps are performed:

- The charging station (in mode 2 the control device is in the charging cable) checks the connection of the PE conductor to the vehicle and transmits the available charging current.
- The vehicle adjusts the charger accordingly.
- The vehicle interlocks the charging connector and requests the start of charging. The charging station interlocks the infrastructure charging connector.

All communication signals are transmitted to the charging station via the CP conductor. If all other requirements are fulfilled, the charging station energizes the connector. The earth conductor is monitored for the duration of charging via the PWM communication. At any time the vehicle can communicate with the charging station and cut power supply. If the vehicle ends the charging process the interlock can be unlocked.

The vehicle charger defines the charging process and its parameters. To prevent the vehicle charger from exceeding both the capacity of the charging station and the charging cable, the capacity of the systems is identified through the resistance in the CP lead. Prior to starting the charging process, the resistance can be determined by the on-board charger by observing the voltage levels.

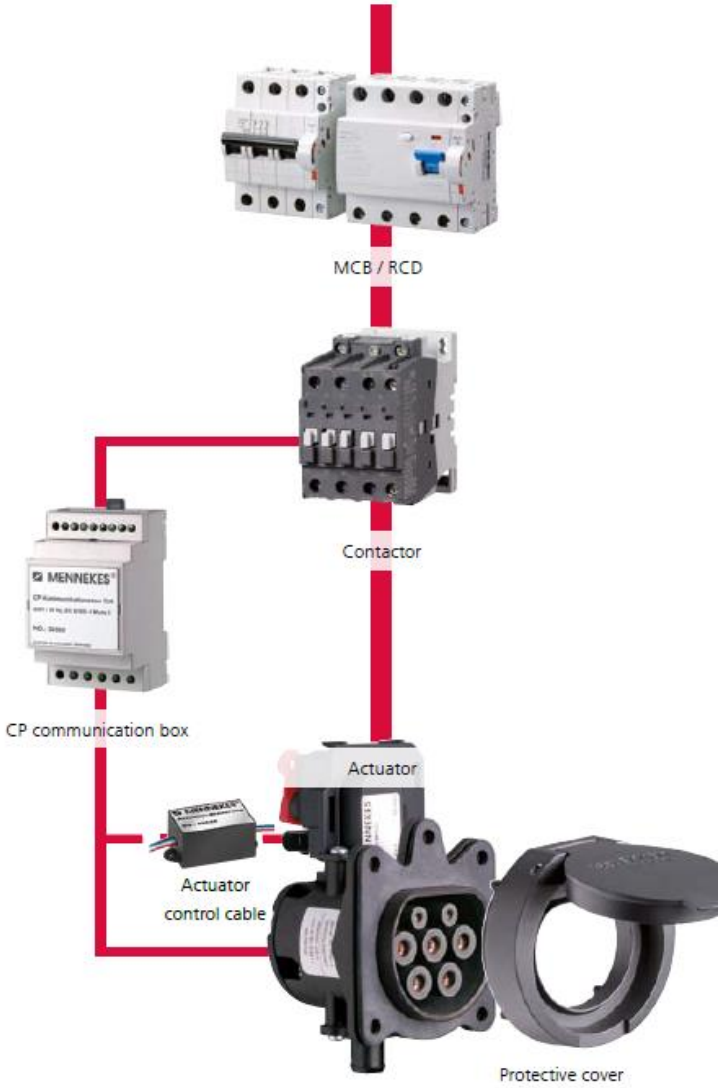


Figure 21. Basic mode 3 charging station components [26]

Moreover, public charging stations should be equipped with the energy management system that on the basis of contract between the EVSE provider and the DSO is responsible for preventing EVs from overloading power grids while charging (especially in case of high power charging stations where numerous EV can be connected).

Those functions are provided by internal subsystems such as:

- operator interfaces for local management,
- web servers for remote connection,
- power meters,
- industrial computers,
- communication interfaces (Ethernet, RS-485/RS-232, CAN, etc.)
- RFID (Radio Frequency Identification) card readers,
- sensor and actuators, etc.

Charging station can be linked to IT systems in a variety of ways. Often a wide range of protocols and interfaces are supported, such as OCPP, Modbus, and SQL.

More complex charging stations dedicated to public use require extended control functions for:

- internal monitoring and control (also described in IEC 61851),
- communication with charging station external service, monitoring and billing systems.

Although both types of stations can be equipped with advanced options, the latter might require cluster management systems securing power management and enabling advanced ancillary services for the network operator.

EXAMPLES OF MARKET AVAILABLE AC CHARGING STATIONS AND THEIR MAIN FEATURES

<u>Examples of charging stations dedicated mainly to private/home charging</u>

- GE WattStation Wall Mount [27], Figure 22

Figure 22. GE DuraStation EV charging station [27]

Main features and functionalities:

  - AC Max Charging Power Output 7.2 kW (240VAC @ 30A).
  - Vehicle Interface SAE J1772 EV connector.
  - Simplicity: charging starts just after the EV is connected. A green backlit charging icon will illuminate to signal that the EV is in the process of charging. When charging is complete, users simply wrap the cord around the charging station, keeping it organized and out of the way.
  - Reduced Energy Consumption: Completely shut off power to the WattStation, ensuring zero energy consumption when not in use.
  - Designed for both indoor and outdoor installation.
  - The WattStation wall mount can either be hard wired for more permanent installations or plugged in for simple removal of the unit.
  - Standards Compliance: SAE J1772; NEC 625; UL 2231, 2251, 2594; NEMA and NIST; cUL 2594 and 2231.
- KEBA KeContact P20 [28], Figure 23.

Figure 23. KEBA KeContact P20 charging station [28]

Main features and functionalities:

- Rated current (configurable connected load): 10A, 13A, 16A, 20A, 25A or 30/32A
- Network voltage: 3x 230-400V / 208-240V
- Network frequency: 50 Hz / 60 Hz
- Overvoltage category: III pursuant to EN 60664
- RCD and MCB in house installations
- Potential-free output
- Socket variations: Type 2 standard socket: 32A / 400 VAC pursuant to EN 62196-1 and VDE-AR-E 2623-2-2
- Cable variations: Type 1 cable with 32A / 230 VAC pursuant to EN 62196-1 and SAE-J1772, Type 2 cable with 32A / 400 VAC pursuant to EN 62196-1 and VDE-AR-E 2623-2-2
- Wall installation both in- and outdoors, optional installation on a pedestal
- Standards and directives
- Directives: 2004/108/EG, 2006/95/EG, 1999/5/EC R&TTE
- Standards Europe: IEC 61851-1, IEC 61851-22, IEC 62196-2, DIN EN 61439-1, IEC 61439-7, EN 61000-6-1,EN 61000-6-3
- Standards US/Canada: SAE J1772, UL 2594, UL 2231-1, UL 2231-2, CSA107.1, NEC, CFR

Additional options

- Identification using RFID pursuant to ISO 14443 for Mifare product family RFID tags (e.g. Mifare 1K)
- Authorization using a key switch
- Ethernet connection (RJ45) for debugging
- Ethernet connection LSA+ clamps for networking with the KeContact M10 (load management system) or for future smart home integration

<u>Examples of charging stations dedicated mainly to public charging</u>

- GE DuraStation EV charger [29], Figure 24

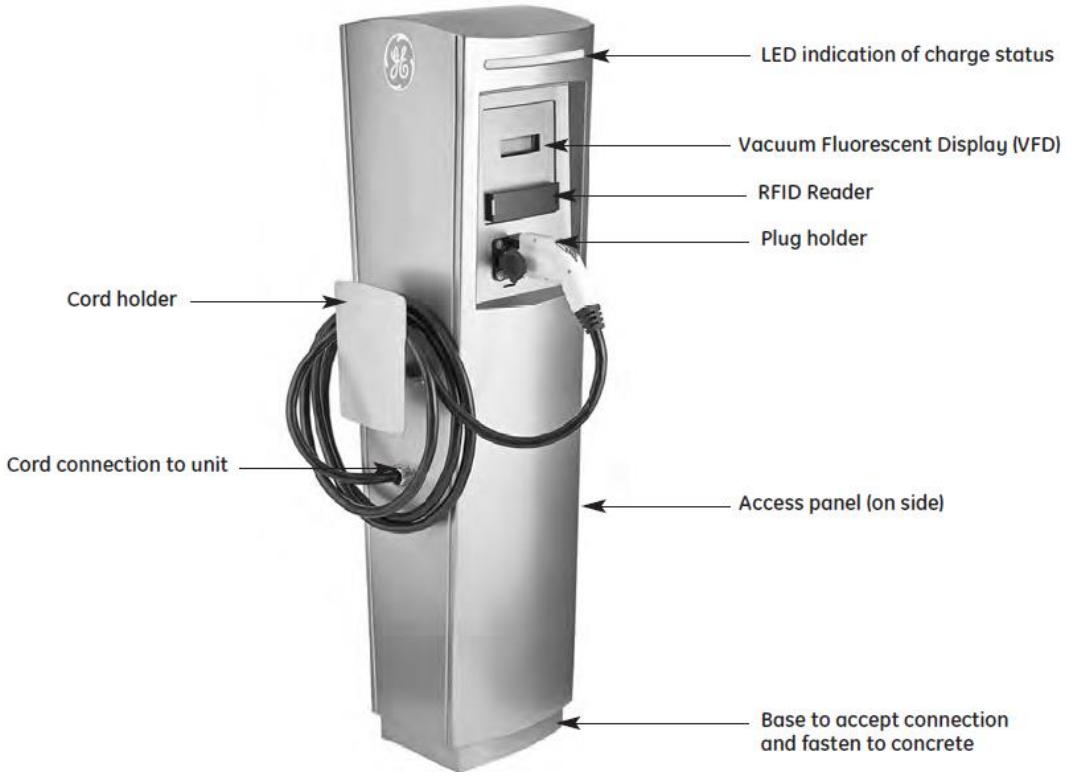


Figure 24. GE DuraStation EV charging station [29]

Main features and functionalities:

- AC Charging Power Output 7.2kW (230VAC @ 32A)
- Type 2 socket/connector with a pilot and proximity contact as per IEC 62196
- LED light to display charger status
- Option for RFID reader
- Ethernet network offered for RFID authorization service
- RFID software application registers usage of the DuraStation, enabling data collection, and will also monitor status of communication between RFID and charging station
- Display (VFD) screen showing greetings, instructions and charging station messages
- Nuisance tripping avoidance and auto re-closure
- Vehicle ground monitoring circuit
- Single phase metering, displayed on included VFD
- A building ventilation interface signal can be provided to operate facility and garage fans when required

- RWE eSTATION [30]

Figure 25. RWE eSTATION [30]

Main features and functionalities:

- Can be operated using 400 V AC, three phase, 16 A (11 kW): also with alternating current 230 V AC, single phase,
- Charging Mode 3 as per IEC 61851
- Plug connection - EC Type 2 plug connection in accordance with VDE-AR-E 2523-2-2 with automatic connector interlocks
- LEDs display (information given such as: Device ready to operate, Vehicle connected, Active charging process, Charging not possible)
- Authentication/Activation via separately switchable key switch for every charging point
- ISO 15118 communication for Smart Charging,
- Communication controls the charging power via the pilot signal according to IEC 61851:2001/SAE J1772:2001
- possible integration of IT-Beckend

DC charging

At present there are two main DC charging standards [31]:

- CHAdeMO – supported Nissan-Renault, Mitsubishi, Subaru, Citroen, Peugeot
- Combined Charging System (for AC and DC charging) – supported by Audi, BMW, Chrysler, Daimler, Ford, General Motors, Porsche and Volkswagen in Europe. The CCS is based on IEC 62196-2, AE J-1772 standards.

DC charging stations offer similar features to the advanced AC Mode 3 counterparts however the power control unit and AC/DC and DC/DC converters are located outside the vehicle, see also Figure 26. Additionally, in case of Mode 4 infrastructure the cable and the vehicle connector should be permanently attached to the charging station.

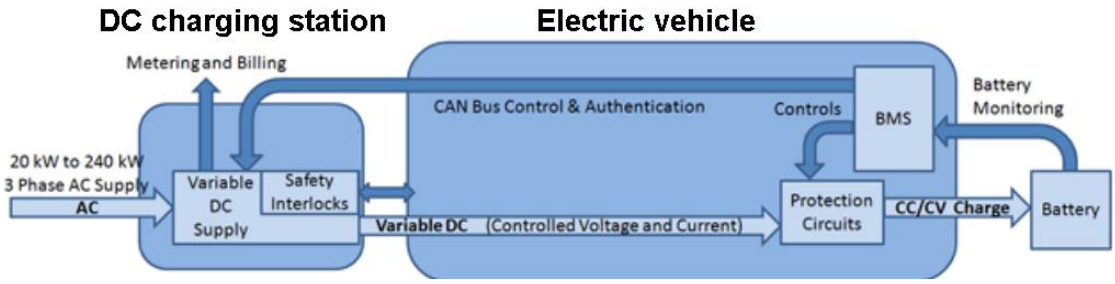


Figure 26. Key components of the DC charging station and EV internal battery management system

During the DC charging the EV's BMS system must communicate with the charging infrastructure to control the voltage and current delivered to the battery. It monitors the key battery operating parameters (voltage, current and temperature and the charging rate) to provide the charging station with required charging profile. If the battery's operating limits are exceeded, the BMS can trigger the protection circuits and end the charging process. Typically, this type of charging stations are designed to support high-power energy flow and enables fast charging.

In Figure 27 a detailed charging sequence is presented on the basis of CHAdeMo standard.

Since CHAdeMO and CCS are non-compatible standards there are charging stations dedicated to one of them. Recently, also charging stations that support both standards were introduced, see Figure 28.

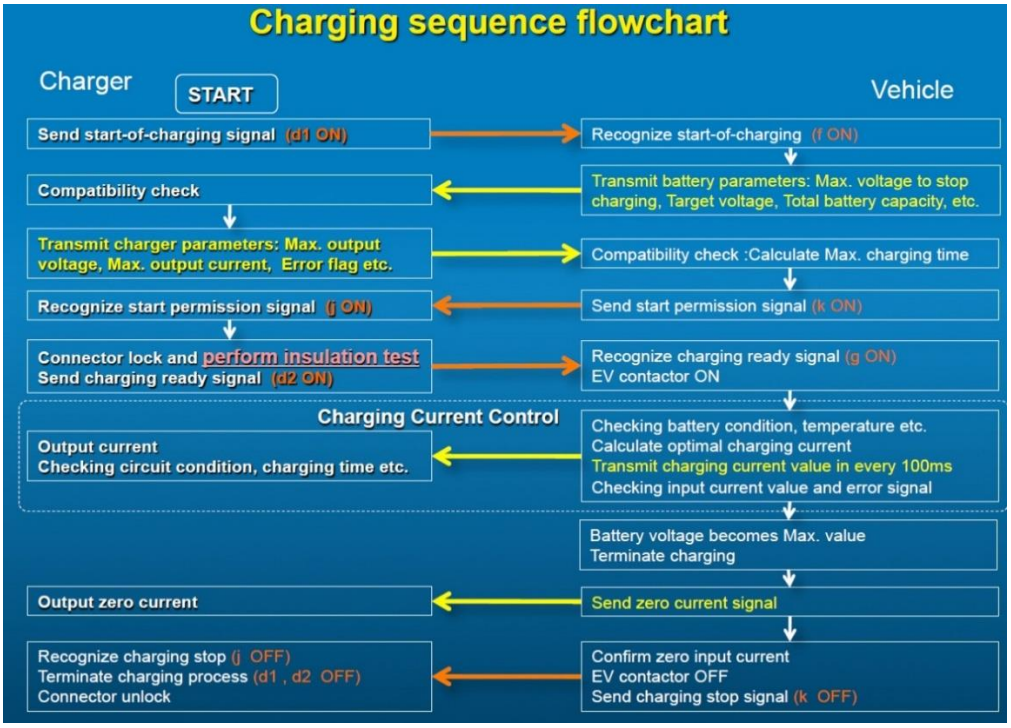


Figure 27. DC off-board charging sequence flowchart [32]

Figure 28. Connectors: Mennekes Type2 (for CCS AC charging) - left, CHAdeMO (for DC charging) – centre, Combo2 (for DC charging) - right

Examples of DC charging stations and their main features

- Schneider EVlink Fast-Charging Station [33]

Figure 29. The Schneider EVlink CHAdeMO charging station [33]

Main features and functionalities:

- CHAdeMO connector and protocol supported
- Charges 80% of the battery in less than 30 minutes

- RFID key for authentication
- GPRS communication
- Remote services for management and maintenance
- Designed for sheltered outdoor use
- Charging access: restricted or pay-per-use

- Blink DC Fast Charger [34]

Figure 30. The Blink CHAdeMO charging station [34]

Main features and functionalities:

- CHAdeMO connector and protocol supported
- Mobile-phone based payment options, and credit card payments
- Advertising revenue and messaging opportunities via the colour LCD display and sound system available through the Blink Advertising Network
- LCD touch screen display
- Programmable start/stop timing
- Beacon light and window for increased visibility
- Exterior treatment and graphics fully customizable for rebranding
- Dual ports for increased user access and availability
- Simplified 2-piece design; separate Grid Power Unit (GPU containing the power electronics) and charging station for ease of installation
- Long reach cable configuration
- Safe, easy-to-use docking connector which prevents accidental disconnection and de-energizes when not in use or incorrectly connected
- Safe in wet or dry use
- Cable and connector can withstand being driven over by vehicle.

- Certified energy and demand metering; supports electric utility EV building when certified to ANSI 12.20 and IEC standards
- Web-based information delivery
- Multiple modes of communications are supported, including Wireless IEEE 802.11g, cellular, LAN/Ethernet, and LAN capable Web-based bi-directional delivery and data flow
- Access to the 'Blink Network' and Blink Membership portal'

The additional specifications of some market available DC charge stations are presented in tables 5, 6, 7 and 8.

Figure 31. The RWE charging station [35]

Table 6. Overview of RWE charging stations [30][35]

Model	eBOX	eSTATION	eBOX SMART	eSTATION SMART	eSTATION COMBI
No. of charging points	1	2	1	2	2 (1 AC and 1 DC)
Charging Mode	3	3	3	3	3,4
Connector type	2	2	2	2	2, Chademo
Max output power [kW]	11	2 x 11	22	22	22 for AC, 50 for DC

Model	eBOX	eSTATION	eBOX SMART	eSTATION SMART	eSTATION COMBI
Max output current	16 A	16 A	32 A	32 A	32 A AC
Rated voltage [V]	230	230	230/400	230/400	230/400 for mode 3
Standard to follow	IEC 61851	IEC 61851	IEC 61851	IEC 61851	IEC 61851
Typ of current	AC single phase	AC single phase	AC three phase	AC three phase	AC and DC
Type of fixing	Wall mounted	Free-standing	Wall mounted	Free-standing	Free-standing

Table 7. Specification of Terra 23 (ABB) charge station [31]

Terra 23				
Outlet specifications	C (default)	J (option)	G (option)	T (option)
Charging Standard	CCS	CHAdeMO	Fast AC cable	Fast AC socket
Max output power	20 kW	20 kW	22 kW	22 kW
Output valtage range	50-500VDC	50-500VDC	400 V +/- 10%	400 V +/- 10%
Max output current	50ADC	50ADC	32 A	32 A
Connection standard	EN61851-23/ DIN70121	CHAdeMO 1.0	EN61851-1:2010	IEC61851-1:2010
Connector/socket type	Combo-2	CHAdeMO/JEVS G105	IEC 62196 mode-3 type-2	IEC 62196 mode-3 type-2
Compatible car brand	BMW,VW, GM,Porsche, Audi	Nissan, Mitsubishi, Peugeot, Citroen, Kia	Renault, Daimler,Tesla	Renault, Daimler,Tesla
Network connection	GSM/CDMA/3G modem, 10/100 Base-T Ethernet			

Figure 32. ABB Terra 53 series with different connectors options and its combinations: Type2 , CHAdeMO and Combo2

Table 8. Specification of Terra 53 (ABB) charge station

Terra 53				
Outlet specifications	C (default)	J (option)	G (option)	T (option)
Charging Standard	CCS	CHAdeMO	Fast AC cable	Fast AC socket
Mode	4	4	3	3
Max output power [kW]	50	50	43	22
Max output current	125 A DC	120 A DC	63 A AC	32 A AC
Output voltage range	50-500VDC	50-500VDC	400V +/- 10%	400V +/- 10%
Connection standard	EN61851-23/ DIN70121	CHAdeMO 1.0	EN61851-1:2010	IEC61851-1:2010
Connector/socket type	Combo-2	CHAdeMO/JEVS G105	IEC 62196 mode-3 type-2	IEC 62196 mode-3 type-2
Compatible car brand	BMW,VW, GM,Porsche, Audi	Nissan, Mitsubishi, Peugeot, Citroen, Kia	Renault, Daimler,Tesla	Renault, Daimler,Tesla
Network connection	GSM/CDMA/3G modem, 10/100 Base-T Ethernet			

Table 9. Overview of ENTSO-E charging stations

Model	Mode	Connector type	Rated current [A]	Rated voltage [V]	Standard to follow	Typ of current	Type of fixing
Home charging							
EVH020.01	3	1	16	230	EN 61439-3	AC 50Hz	Wall mounted
EVH020.02	3	2	16	230	EN 60439-3	AC 50Hz	Wall mounted
Free slow charging connection to Automatic Payment System (APS)							
EVT160.11		domestic socket-outlet (typ F,E,G)	16	230/400	EN 60439-3	AC 50Hz	Ground mounted
EVT160.12			2x16	230/400	EN 60439-3	AC 50Hz	Ground mounted
EVT060.11			16	230-400	EN 60439-3	AC 50Hz	Wall mounted
EVT060.12			2x16	23/400	EN 60439-3	AC 50Hz	Wall mounted
Station where advanced user identification and data communication is required (e.g. billing).							
EVC100.xx	1,3	2,3	16/32	230/400	IEC61851-1, EN60439-1/-2	AC 50Hz	Ground mounted
EVC200.xx	1,3	2,3	16/32	230/400	IEC61851-1, EN60439-1/-2	AC 50Hz	Ground mounted (dual charging stations)
EVC050.xx	1,3	2,3	16/32	230/400	IEC61851-1, EN60439-1/-2	AC 50Hz	Wall mounted
Compact wall or pole mounted charging point							
EVP050.12	1,3	F Schuko	16	230/400	EN 60439-3	AC 50Hz	Wall mounted
EVP050.12-E	1,3	E French	16	230/400	EN 60439-3	AC 50Hz	Wall/Pole mounted
EVP070.01	3	1	16	230	EN 60439-3	AC 50Hz	Wall mounted
EVP070.12	3	2	32	230/400	EN 60439-3	AC 50Hz	Wall mounted
EVP070.13	3	3	32	230/400	EN 60439-3	AC 50Hz	Wall/Pole mounted

2.3.3.2 **Wireless charging**

Wireless (inductive) charging is a relatively new technology and still in testing stage. It has been gaining recognition over the past few years as a possibly convenient way to charge electric cars. It allows electrical energy to be transferred from the grid to a vehicle without the aid of wires. The wireless charging system uses an inductive power transfer technology (such as in electrical transformers). Using magnetic fields, energy is transferred from the transmitting coil in the parking pad and converted into an electrical current by the receiving coil mounted under the car chassis. In the final step, AC current is converted to DC by on-board rectifier.

Currently, wireless charging is not in common use, nevertheless, it is already commercially available as a third party enhancements e.g. Evatran's Plugless system for Nissan LEAF and Chevrolet Volt. It is also being tested by some car manufacturers such as Volvo, Nissan and Toyota.

The dedicated standard IEC 61980 (Electric vehicle wireless power transfer systems) is under preparation.

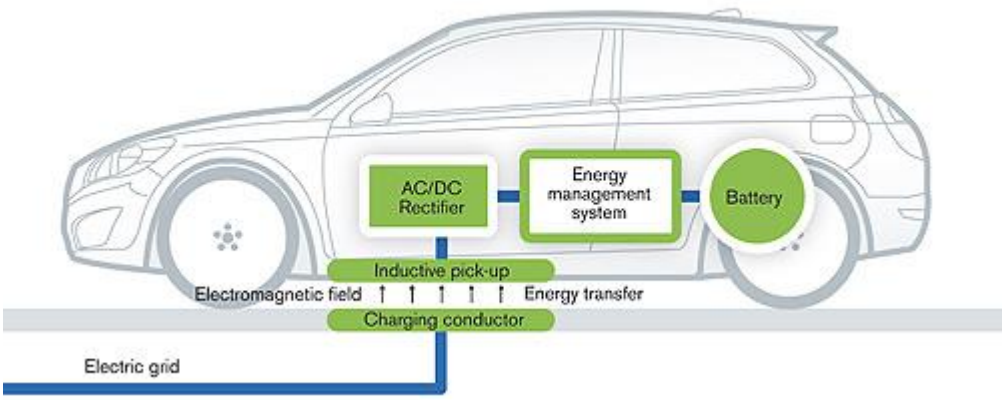


Figure 33. Graphic illustration of wireless EV charging [36]

2.3.3.3 **Battery swap**

One of the solutions facilitating long distance trips and fast 'battery charging' is the technology known as a battery swap. Although this solution will not be further investigated in COTEVOS, it is presented for completeness of the state of the art analysis.

The idea behind the battery swap technology is to open the car chassis to pull the battery out and replace it with a fully charged one. The process should take a couple of minutes and can be fully automated and robotized.

The main disadvantage is that swap stations should be able to exchange different types of batteries in compliance with different procedures. Also, such stations should be equipped with a wide range of battery types (for different vehicles), which significantly increases overall costs and payback time.

Battery swap technology involves some additional issues such as:

- lack of unification of battery sizes, capacity, charging profiles,
- difficulty in estimating how deeply a battery pack is worn or how battery effectiveness is reduced (risk of fraud),
- who should be the owner of battery. Owner of new vehicles can be unwilling to exchange their new batteries with old ones.

Regardless of those problems, companies such as: Better Place (already went bankrupt) and Tesla Motors successfully demonstrated battery swap. Due to high costs the future of this technology is uncertain.

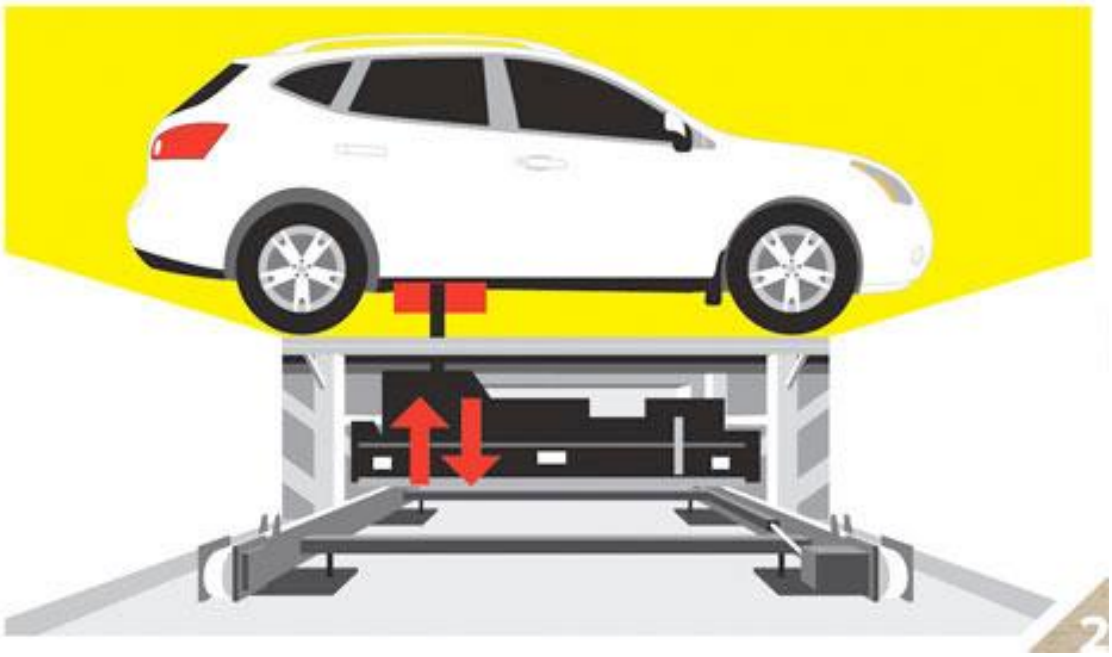


Figure 34. Concept of battery exchange station presented by company Better Place [37]

2.3.4 Connection to the electricity grid – DSO perspective

Connection to the electricity grid is considered only for a low voltage network as all charging access points and charging stations (home and public) are directly connected to LV buses. Therefore, the configuration and operation parameters of LV network together with management operation such as measurements, development, etc. are most important for e-mobility.

The MV network aspect should be considered only in case of large penetration of EV systems, which nowadays cannot be achieved. In case of centralized group of charging stations such as fleet car park or shopping mall car park, especially for DC charging stations, a separated MV circuit with MV/LV transformer (separated secondary substation) should be considered, even though it will be only some additional load for MV network. Therefore, in D1.1 the MV network aspect is not considered.

A low voltage network is a part of the distribution system. This part of power system is subjected to the Distribution System Operator (DSO). It is responsible for the network

maintenance, operation and development. Therefore, an approach of the DSO to e-mobility is highly important.

From the DSO perspective the EN 50160 standard is the basic standard which DSO has to comply with. The second precondition is the access to the bi-directional data flow between EV, EVSE, aggregator and SCADA system with the local management possibilities. For further development of the grid it is necessary to enable the autonomous management and operation of the microgrid.

Connection to the grid is not directly relevant for interoperability. However, some aspects of the network design, equipment and operation significantly affect e-mobility, especially additional services such as V2G or Smart Charging and the comfort of the EV use (this point refers to the EV users). Such services require bi-directional power flow, which can be an issue for the grid and its protection equipment (voltage, protection coordination).

Increasing penetration of the EV may change the way how distribution system is operated and planned. Although, EV can be treated as additional load it has own characteristics and in fact does not behave as a typical load (as the lighting for example). EV may affect voltages, voltage/current THD and asymmetry. Moreover, user in order to contribute to the e-mobility development must be convinced that EV is reliable option for transportation. The grid configuration together with equipment and telemechanics stands for the network outages probability and, therefore, indicates what is the probability that EV users cannot charge the vehicles. Higher outage probability does not support EVs.

2.3.4.1 **Configuration and operation of LV networks**

Generally, the connection of EV, particularly EVSE, to the LV grid can be carried out in any part of the network. Therefore, it is advisable to consider all possible network configuration and operation states. The network configuration, which depends mostly on the geographical location and demand, influences the reliability of the electricity supply and overall available level of the EVSE integration. The more network configuration is complicated, reliability increases – network switching is available and prevents from long interruptions for electricity supply. More advanced grids operated in the mesh structures presents the higher potential for the EV integration. The network type results with the equipment installed – protection and control. Services such as V2G and Smart Charging are sensitive to them.

According to network configuration and operation, LV grid is subdivided as follows:

1. Single fed networks – networks supplied from a single source with no mesh:
    a. Simple radial networks,
    b. Branched radial networks.
2. Bus networks – networks supplied from one or more sources:
    a. Loop networks,
    b. Tree networks,

c. Grid networks.

Single fed LV networks

These networks are simple and well-arranged. Each feeder has its own circuit-breaker; the selectivity of the protection level can be achieved by installing fuses with different rated current values. Their main disadvantage is that no substitution is given in case of a line failure. Losses are also higher than with bus networks and voltage tends to fluctuate when large consumptions are switched. The main disadvantage is fluctuation of voltage and low reliability of electricity supply.

These networks can accommodate EVs only in low quantities. Because the network reliability is low, users often experience interruptions in electricity supply. From the e-mobility and EV user perspective, outages in the grid results with the lack of the mean of transport. These networks are typical in the rural areas.

Bus LV networks

Reliability of electricity supplies, as well as higher operation and safety requirements are common for these networks.

Loop networks

This network is supplied from a single transformer station and forms an enclosed mesh. Loop networks are supplied from two sides. The main advantage of such configuration is that in case of a failure, the switchgear can also be supplied from the other side (in such a case, the loop line is divided into two single circuits supplied from one side). The voltage reliability in such networks is higher and when compared to single fed LV networks, losses are also lower. The disadvantage is that higher safety levels are required during work on live lines due to threat of reverse currents caused by supply from both sides.

Tree networks

These networks are created when several loop lines are interconnected. This results in a higher level of electricity supply reliability, improved stability of voltage and lower losses. The main disadvantages are that tree networks are complex, complicated and demand higher operational skills.

Grid networks

Grid networks are created by linking interconnected networks into meshes. They always have no less than two MV feeders. Out of all network configurations, grid networks provide highest reliability of electricity supplies, lowest possible losses and stable voltage. The entire network is constructed of conductors of an equal cross-section and fuses of an equal rated current are used in all buses of the grid network. The main disadvantage is that these networks are complex, complicated and difficult to operate. This type of network is typical for the urban area, especially in cities and their centers. They are able to accommodate the largest number of EVs without negative results for the power system. Grid networks are considered as the robust and should be enough for the e-mobility services after modernization applied to the protection devices.

2.3.4.2 **LV network bi-weekly load profile**

The Figures 35 and 36 below show measured electricity consumptions by municipality a bi-weekly profile. These specific measurements reflect the summer period with increased power consumption due to the increase of the outside temperature (maximum over 37 degrees Celsius). There are visible differences between the municipal consumption profile and the business centre consumption profile. Municipal consumption including shopping and business centres is more sensitive towards the temperature change and during the extreme summer period the power output increased by 25-30% (mainly due to the air-conditioning). On the other hand, the rural and suburb consumption profile showed less sensitivity with only limited increase of the consumption (households with higher income due to domestic air-conditioning equipment are an exception).

This conclusion is important when modelling the potential power consumption influenced by the new type of the consumption – electric vehicle.

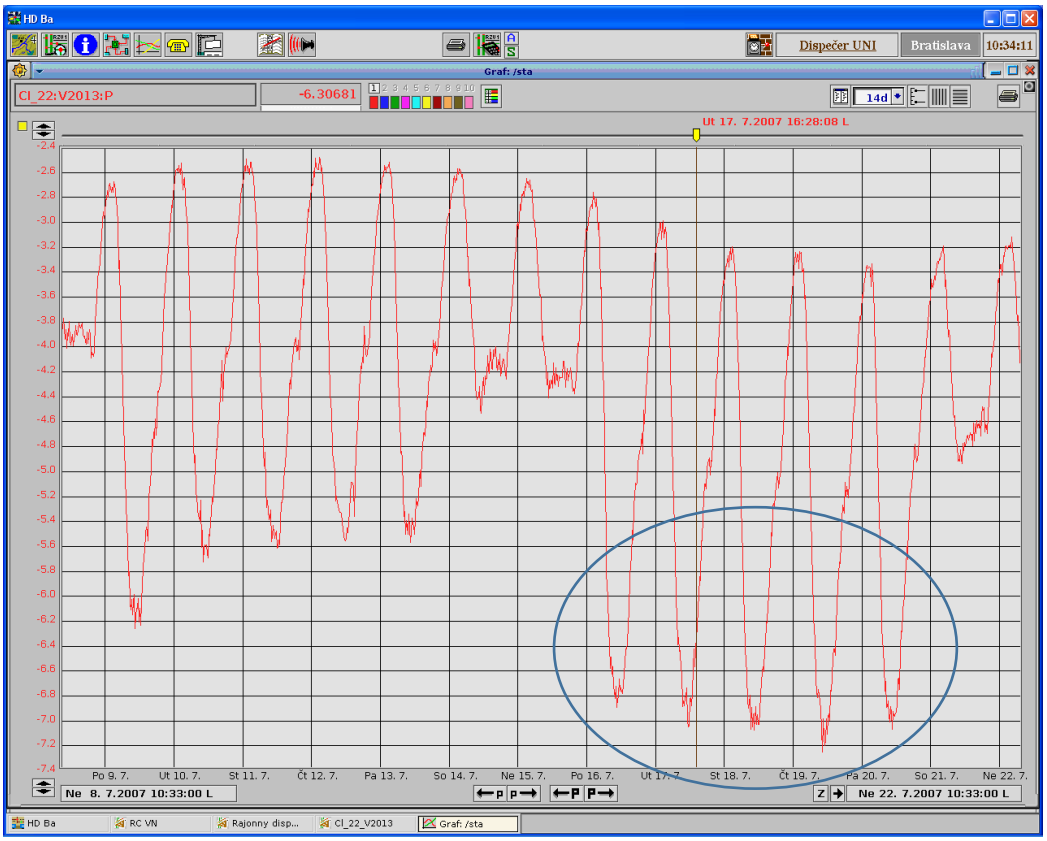


Figure 35. Typical power consumption of the municipality: x axis – date, y axis – power output

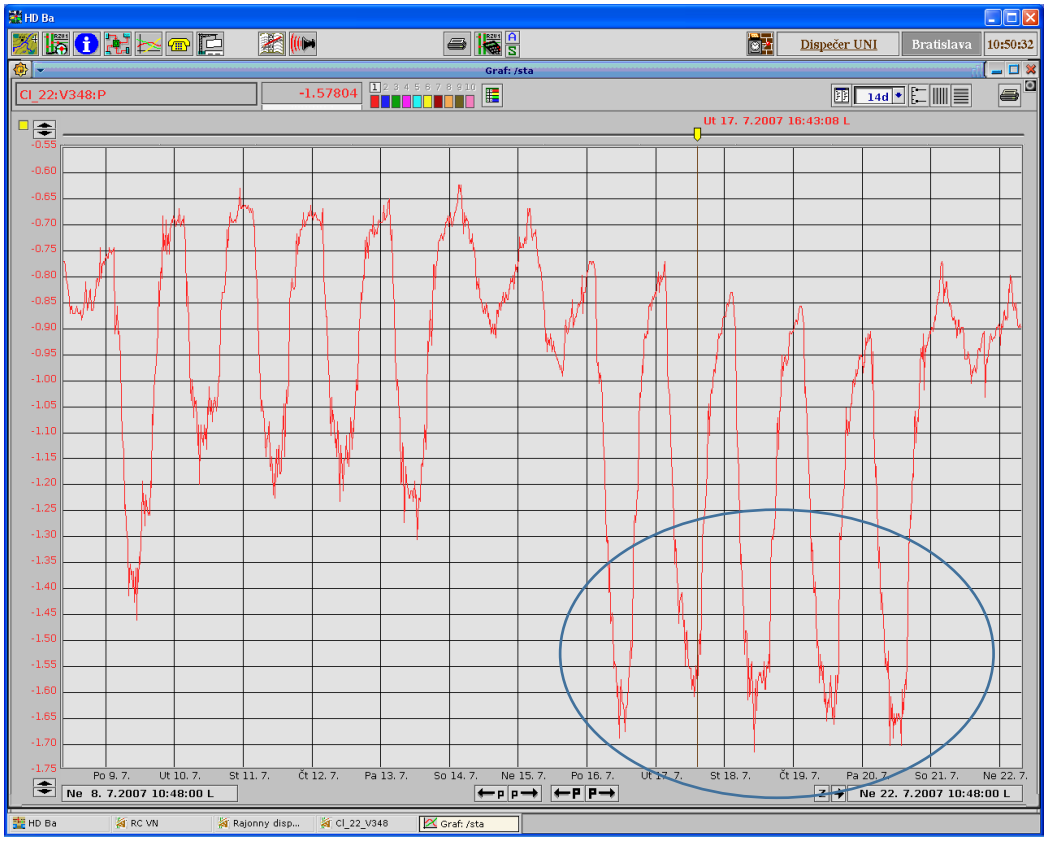


Figure 36. Typical power consumption of the business centre object
x axis – date, y axis – power output

2.3.4.3 **Grid development**

From the DSO point of view, EVs with charging stations can represent a tool for the grid management. This shift is connected with the responsibility for the deviation of transfer, where an extended involvement of the DSOs in the future is expected. DSOs prefer the network regulation execution at the local level, copying the logical structure of the distribution network. Therefore, the main component is the regulation at the substation level (e.g. 22 kV/0,4 kV).

Any kind of grid regulation is strongly linked with the communication and the access to real data. The bi-directional data flow between EVs, EVSE, back-end system, aggregator/EVSP and SCADA system are the precondition for the utilization of Smart Charging. For the communication behind the substation the PLC meets all current requirements. There is a correlation between the Smart Metering concept and e-mobility, as the logic of data gathering is similar. Therefore, synergies of both are highly recommended. From the DSO point of view, the online access to information on the LV level is the precondition for further smooth integration of charging services (and EVs, including V2G and Smart Charging) and renewable energy sources. In this environment the extension of the existing SCADA system is compulsory, since already operating SCADA systems are a dominant tool.

New intermittent/non-predictable electricity generation from renewable energy sources connected mainly to the LV network is changing the situation with the grid management as such. To manage the grid, it is important to:

- Clearly identify generation sources at all voltage levels
- Obtain on-line measurement of the actual energy flows in the grid (production/consumption)
- Obtain on-line measurement of network parameters
- Obtain the option to remotely disconnect a generating source of electricity
- Support the security of on-site technicians/maintenance staff

Main challenges linked with the LV network management are:

- Lack of information about real network connections at the local scale
- Insufficient support for the outage management and planned maintenance
- Complicated system support
- Lack of information about connected generation sources
- Integration of data from the Smart Metering

To solve the above mentioned challenges it is important to integrate the LV network into the existing SCADA system, with the unified environment for management of all voltage levels – LV, medium-voltage and high-voltage. With this system DSO is able to get up-to-date information from the grid. The integration with the Smart Metering will lead to the increase of network security and reliability. At the same time it is necessary to upgrade the existing SCADA system with the incident management module and provide unified system support for the outage management and for planned maintenance. Only such approach will provide required background for all new services planned for both renewable energy sources, distributed generation and e-mobility (V2G, Smart Charging). Without proper measures it is impossible for to DSO to handle network operation.

The only way of sustainable expansion of the distribution grid is the development of applications capable of the autonomous management and operation of the microgrid (local part of the distribution network). Information is gathered and then used for the central grid management – information data set necessary for the microgrid:

- available power capacity at given time
- free capacity for the electricity distribution
- production and consumption data
- ability to autonomously identify local outage and separate it from the rest of the grid
- outage information flow to the work-force management tool

2.3.4.4 **Impact of private charging on the electrical network**

Home or private charging basic connection represents 16 A and 230 V parameters, with the theoretical output of 3,7 kW. For this charging process the home installation and local limitations is the basic framework.

The example of charging process is shown on the Figure 37.

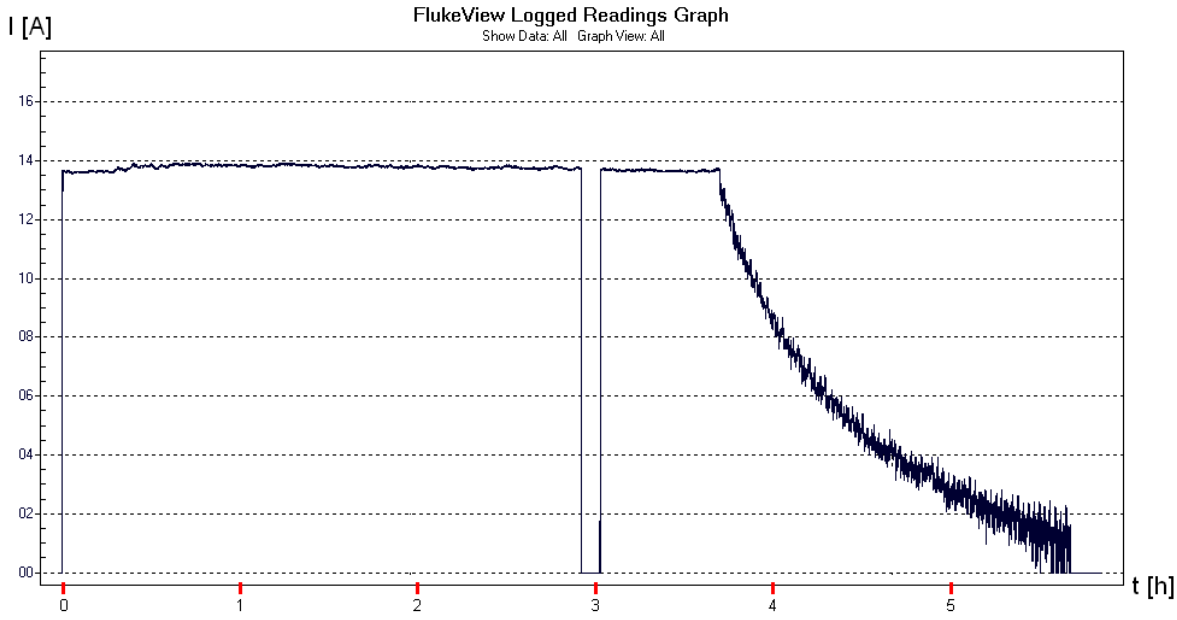


Figure 37. Domestic charging process (16Ax230V)

In the grid there were no negative impacts of the charging process recorded. Harmonics and flicker severity factor P_{st} are shown in the next table.

Table 10. Domestic charging process measurements

U_{L1}	Before charging		During charging	Limits
P_{ST}	0,07		0,18	1
THD [%]	1,9		2,2	8
3.harmonic [%]	0,4		0,3	5
5.harmonic [%]	0,8		0,6	6
7.harmonic [%]	0,9		1,1	5

2.3.4.5 **Impact of fast charging**

A fast charger with 50 kW of power output is usually connected to the 22 kV/0.4 kV (630 kVA) substation. Short-circuit power at the point of charger connection is 2.6 MVA.

The charging process at the fast charging station is presented in the Figure 38.

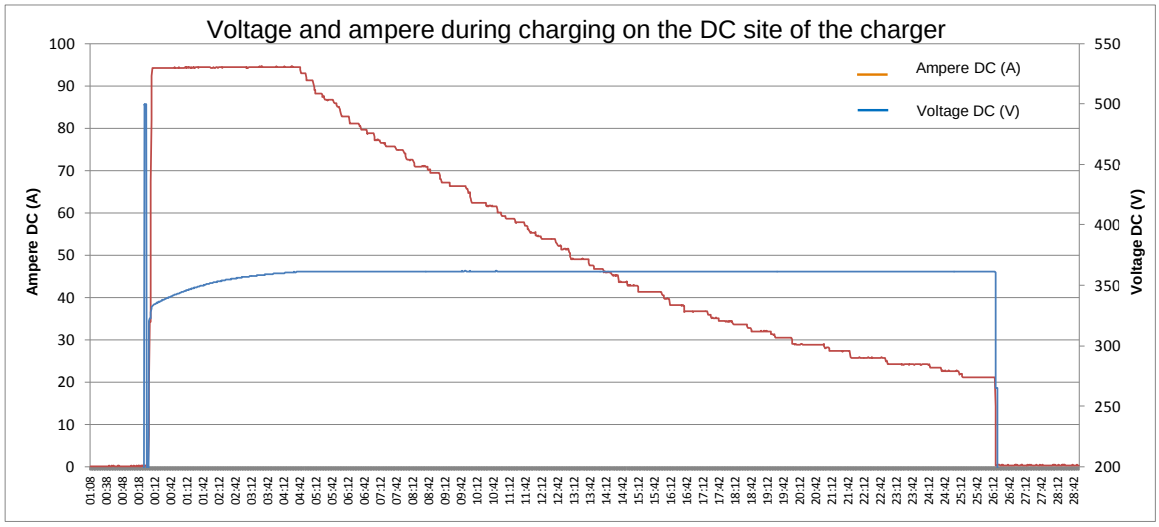


Figure 38. Charging process at the fast charger

Measurements of the charging process confirmed the fast charger have compensation of reactive power. This compensation is designed for compensating maximum power. A decrease in output power causes a decrease in the power factor. A problem with reactive power and power factor is considerable in this case and has to be solved as losses and costs increase. It is extremely important issue for the DSO. If the power factor decreases, the current in line increases due to the reactive component. It limits the power capacity of the line and leads to the ineffective network use. It is an issue for interoperability between the EVSE and grid.

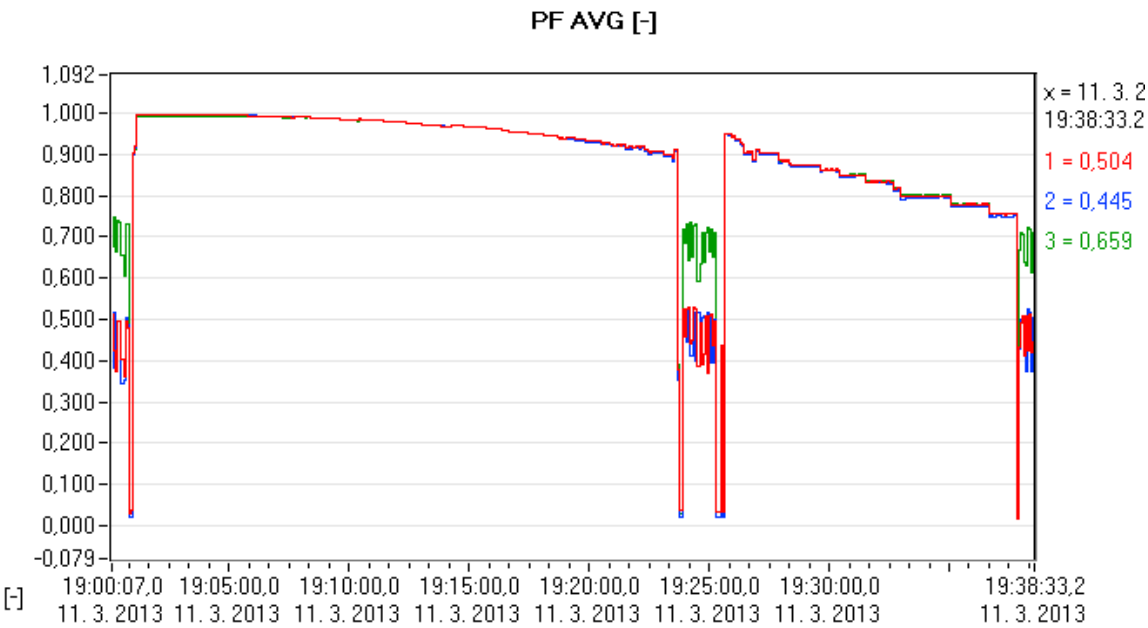


Figure 39. Power factors during charging with charging station ; x axis – time (t), y axis – power factor (PF)

In general, we can say that the fast charging process does not negatively affect the distribution network. On the other hand, there is a strong correlation with the quality of

the distribution grid and we suggest keeping the Short-circuit power at least at the level of 0,7 MVA.

2.3.5 EMC for EV charging systems

The concept of electromagnetic compatibility (EMC) regards the protection of EV's electric circuits and communication systems from the negative impact of electromagnetic disturbances that occur in supply networks during a charging process. It also refers to the limitation of disturbances coming from the vehicle itself or from a charging station. To ensure EMC means to maintain introduced disturbances within permissible limits and to operate correctly within an electromagnetic polluted environment.

The Directive 72/245/EEC [38], which is currently effective, including its amendments contained in the Directive 2004/108/EC [40], sets the following requirements on the survey of the entire vehicle as well as the electrical and electronic sub-assemblies (ESA) to the extent of EMC:

- vehicle survey: emissions of radiated disturbances and immunity to radiated disturbances,
- tests of electronic ESA: emissions of radiated and conducted disturbances, immunity to radiated and conducted disturbances.

EMC aspects of connecting EVs to charging systems powered by electrical networks are not included in the Directive.

In order to identify, harmonize and organize the standardization issues related to EV charging, the European Committee authorized the following European standardization organizations: the European Committee for Standardization (CEN), the European Committee for Electrotechnical Standardization (CENELEC) and the European Telecommunications Standards Institute (ETSI) to prepare a report on Standardization for road vehicles and associated infrastructure [6]. In particular, the European Committee advised to consider any hazards to safety and electromagnetic compatibility of EV chargers under the requirements of Directives 2004/108/EC (EMC) [40] and 2006/95/EC (LVD) [41]. The report [6] contains a number of recommendations and their implementation should complete all the gaps in the process of standardization of EMC for electric vehicle charging systems.

It is worth mentioning that pursuant to the Regulation (EC) No 661/2009 of the European Parliament [42] Directive 72/245/EEC [38] shall be revoked as of 1 November 2014 and may be replaced by the Regulation No 10 of the Economic Commission for Europe of the United Nations (UN/ECE) [43]. This document, which is currently verified, covers all aspects of EMC for EV and power network.

This chapter, which corresponds to the range of work anticipated for COTEVOS project, is limited to the analysis of requirements for EMC low frequency phenomena i.e. harmonics and voltage fluctuations.

2.3.5.1 EMC standardization in relation to EVs connected to the network

The issues of EMC of vehicles connected to electrical power network for charging are referred to the International Electrotechnical Commission (IEC), particularly IEC Technical Committee No 69: Electric road vehicles and electric industrial trucks (TC 69). The committee's decisions should make allowance for basic requirements of EMC 61000 series standards which were prepared by IEC TC 77: Electromagnetic compatibility.

Currently, the IEC/TC 69 Committee is developing the following standards on electric vehicle charging systems:

- IEC 61851-21-1, Ed. 1.0: Electric vehicle conductive charging system – Electric vehicle on-board charger EMC requirements for conductive connection to an AC/DC supply,
- IEC 61851-21-2, Ed. 1.0: Electric vehicle conductive charging system – EMC requirements for off-board electric vehicle charging systems,
- IEC 61851-22: Electric vehicle conductive charging system - Part 22: AC electric vehicle charging station,
- IEC 61851-23, Ed. 1.0: Electric vehicle conductive charging system - Part 23: DC electric vehicle charging station,
- IEC 61851-24, Ed. 1.0: Electric vehicle conductive charging system – Digital communication between a DC EV charging station and an electric vehicle for control of DC charging,
- IEC 61980-1, Ed. 1.0: Electric vehicle wireless power transfer systems (WPT) - Part 1: General requirements.

The first two standards are to replace the existing document: IEC 61851-21, Ed. 1.0 (2001): Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply, while the IEC 61980 standard refers to wireless power transfer systems (WPT) when charging with the use of the technology of transferring energy through a magnetic field, electric field or by means of microwave power transfer.

Each of the foregoing standards recommends tests of low frequency electromagnetic disturbances in compliance with the requirements of basic EMC 61000 series standards.

General requirements concerning emission and immunity in different EMC environment are given in EMC 61000-6 series:

- IEC 61000-6-1 Electromagnetic compatibility (EMC): Part 6-1: Generic standards - Immunity for residential, commercial and light-industrial environments,
- IEC 61000-6-2 Electromagnetic compatibility (EMC) – Generic standards – Immunity for industrial environments,
- IEC 61000-6-3 Electromagnetic compatibility (EMC) – Part 6-3: Generic standards – Emission standard for residential, commercial and light-industrial environments.

Specific requirements regarded harmonics emission are given in IEC 61000-3 series standards. Electric vehicle chargers were classified as A class equipment according to the definitions under the IEC 61000-3-2 [44]. Limits for harmonic current emission are dependent on the value of input current. Tests of emissions should be conducted according to:

- IEC 61000-3-2 [44] for equipment with nominal input current ≤16 A per phase, and
- IEC 61000-3-12 [45] for equipment connected to public low-voltage systems with input current >16 A and ≤ 75 A per phase.

Emission limits for voltage fluctuations and flicker are defined in a similar way. Tests of emissions should be conducted according to:

- IEC 61000-3-3 [46] for chargers with the nominal phase currents up to 16 A, and
- IEC 61000-3-11 [47] for chargers with nominal currents of 16 A < I_N ≤75 A.

Limits as provided in the above standards regard individual appliances. The expected large number of electric vehicles charged simultaneously in big car-parks or highways from the same supply network may be the reason for exceeding the given values of emission limits for power networks. This issue should be separately treated using the following standards:

- IEC/TR 61000-3-14: Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems,
- IEC/TR 61000-3-6: Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems,
- IEC/TR 61000-3-7: Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems.

Main EMC requirements for vehicles come from Regulation No.10: Uniform provisions concerning the approval of vehicles with regard to EMC (United Nations) [43] that includes also charging mode EMC compliance as for point 7: Additional specifications in the configuration "RESS charging mode coupled to the power grid" (RESS - rechargeable energy storage system).

General specifications are the following:

- A vehicle and its electrical/electronic system(s) shall be so designed, constructed and fitted as to enable the vehicle, in configuration "RESS charging mode coupled to the power grid", to comply with the requirements of this Regulation.
- A vehicle in configuration "RESS charging mode coupled to the power grid" shall be tested for radiated emissions, immunity to radiated disturbances, conducted emissions and immunity to conducted disturbances.
- Before testing the Technical Service has to prepare a test plan in conjunction with the manufacturer, for the configuration "RESS charging mode coupled to the power grid" configuration which contains at least a mode of operation, stimulated

function(s), monitored function(s), pass/fail criterion (criteria) and intended emissions.

Regulation No. 10 covers vehicle in a driving mode as well as in a charging mode; EMC compliance could be achieved by testing and assessment of the complete vehicle as well by integration of assessed and certified ESA. In general, for new vehicles and for better product functionality and safety a complete vehicle is tested, while certified ESA could be preferred, to save money and time, when only one ESA is changed or modified.

With reference to the charging mode, EMC vehicle compliance and functionality we have to consider a different situation or charging modes.

For AC charging (mode 1, mode 2 and mode 3) with an on-board charger, vehicle charging equipment includes wires, socket, interrupters and fuses, as well as power electronic devices with electronic control unit. In this case a preliminary charger EMC test and assessment as well as an ESA EMC compliance availability check could be preferred to speed up the EMC testing process and to improve safety and functionality in the charging mode. From vehicle/OEM point of view, EMC chargers compliance according to R10 regulation is mandatory.

For DC charging and AC fast charging, vehicle charging equipment includes wires, socket, interrupters and fuses, as well as an electronic control unit embedded on board. In this case, from the vehicle /OEM point of view, major issues refer to off-board charger radiated and conducted emissions and EVSE in general.

Specifications concerning emission of harmonics, as well as voltage changes, voltage fluctuations and flicker include methods of testing and vehicle type approval limits.

2.3.5.2 Methods of testing for emission of low frequency conducted disturbances on AC power lines from vehicle (harmonics and flicker)

Testing of low frequency conducted disturbances emission from EV, as defined in Regulation No. 10, is intended to measure the level of harmonics or voltage changes, voltage fluctuations and flicker generated by vehicle during charging (in configuration "RESS charging mode coupled to the power grid") through its AC power lines in order to ensure it is compatible with residential, commercial and light industrial environments. Tests are done on on-board chargers and involve charging modes 1, 2 and 3; they should be conducted according to the IEC 61000-3 series standards, as described in 2.3.3.2. During tests the vehicle shall be connected to the power grid at rated power until the AC current reaches at least 80 per cent of its initial value.

The test set-up configurations are presented in Figure 40, Figure 41 and Figure 42 in comparison with the ones given in the IEC 61000-3-2 354 [44] and IEC 61000-3-3 [46] Standards.

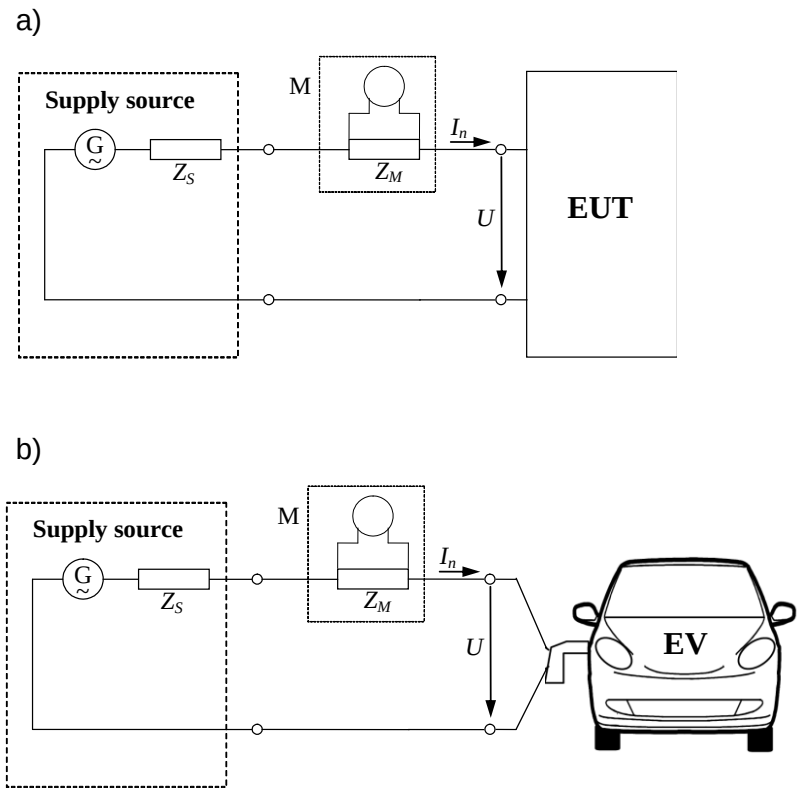


Figure 40. Measurement set-up for the measurement of single-phase harmonic emission according to: IEC 61000-3-2
(a) or Regulation No. 10 (b) Power supply source of internal impedance Z_s and open circuit voltage G, M - measurement device with input impedance Z_M,, EUT - equipment under test, EV - electrical vehicle, I_n - harmonic current, U - voltage

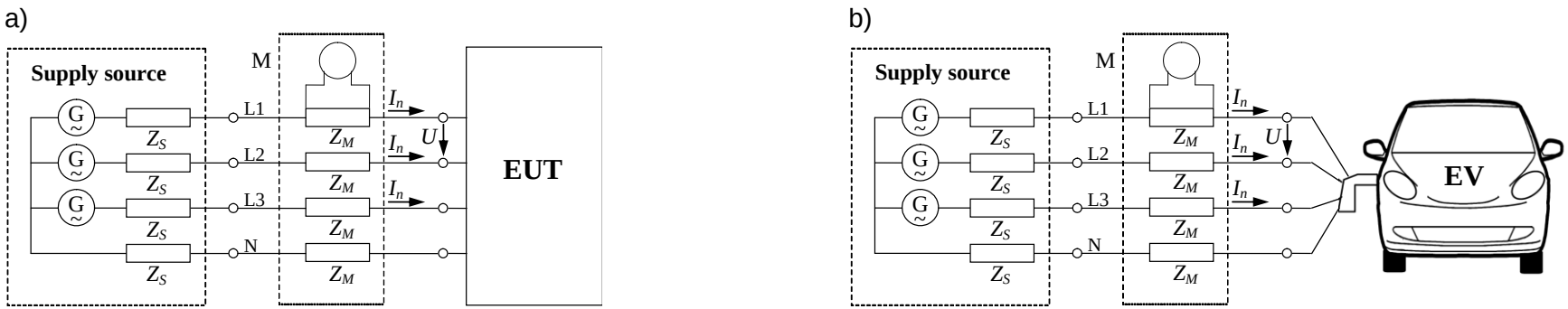


Figure 41. Measurement set-up for the measurement of three-phase harmonic emission according to:
IEC 61000-3-2 (a) or Regulation No. 10 (b);
(Power supply source of internal impedance Zs and open circuit voltage G, M - measurement device with input impedance ZM, EUT - equipment under test, EV - electrical vehicle, In - harmonic current, U - voltage)

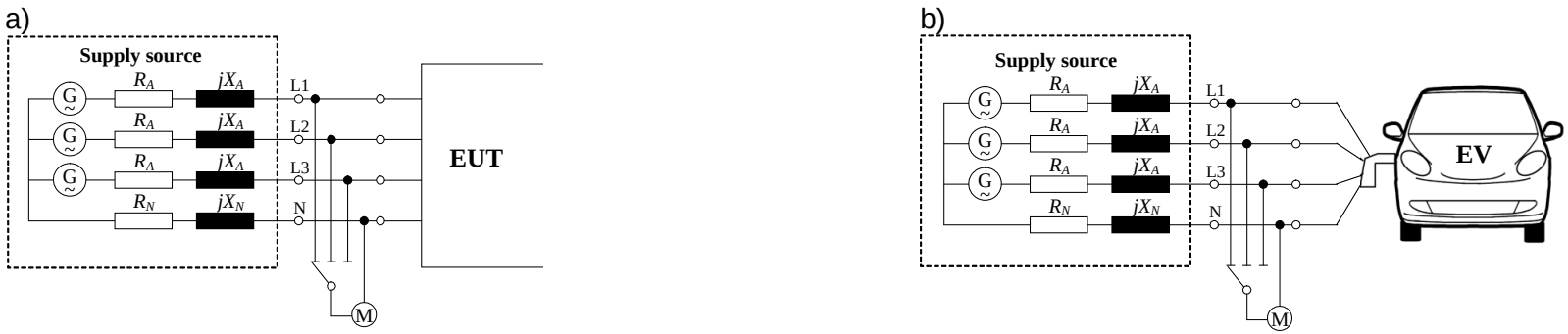


Figure 42. Measurement set-up for the measurement of single-phase and three-phase voltage changes, voltage fluctuations and flicker emission according to:
IEC 61000-3-3 (a) or Regulation No. 10 (b)
(Power supply source of internal impedance $R_a + jX_a$ and open circuit voltage G, M - measurement device with input impedance Z_M,,
EUT - equipment under test, EV - electrical vehicle)

Requirements for emission of harmonics generated on AC power lines from vehicle and requirements for emission of voltage changes, voltage fluctuations and flicker generated on AC power lines from vehicle are included in the Appendix II.

2.3.5.3 Assessment and requirements for emission limits for the connection of disturbing installations to LV power systems

Rules and procedures for the connection of large disturbing installations to LV power systems are the subject of IEC/TR 61000-3-14: Electromagnetic compatibility (EMC) – Part 3-14: Assessment of emission limits for harmonics, interharmonics, voltage fluctuations and unbalance for the connection of disturbing installations to LV power systems [48]. This document defines the principles of cooperation between the DSO and energy customers in determination of emission limits of low-frequency conducted electromagnetic disturbances for individual customers connected to the grid.

The procedure is divided into three stages depending on the apparent power of installation and grid characteristics.

Stage 1: Simplified evaluation of disturbance emission.

This means that small appliances can be installed and connected to the grid without a specific evaluation of harmonics and/or flicker by the DSO. For example, chargers for residential (on-board chargers), semi-public and public charging spots, designed in compliance with IEC 61000-3-2, IEC 61000-3-3, IEC 61000-3-11 and IEC 61000-3-12, can be connected without restrictions.

Stage 2: Emission limits relative to actual system characteristics.

Installations that do not meet the stage 1 must be assessed from the point of view of the impact on the network in terms of harmonics and voltage fluctuations.

For each installation individual disturbances emission limits are determined by DSO, depending on its apparent power and the network conditions. In the area of EV this procedure may be applied for fast charging systems with power ratings greater than 50 kW or dedicated charging stations with multiple chargers.

Stage 3: Acceptance of higher emission levels on a conditional basis.

If the installation does not meet the basic limitations specified in stage 2, the energy consumer and DSO may agree to higher levels of emissions, provided that it does not worsen the conditions of supply of other customers connected to the network. Coordination of individual emission limits of disturbances for each energy customer results from the need to maintain the planned level for the network defined by the DSO.

One or more of the indices can be used to compare the actual emission level with the customer's individual emission limit.

For harmonic emissions the indices are:

- The 95 % weekly value of individual harmonics $U_{h,sh}$ (or $I_{h,sh}$) over "short" 10 min periods, should not exceed the emission limit E_{Uhi} (or E_{Ihi}). E_{Uhi} (or E_{Ihi}) is the individual harmonic voltage (current) emission limit of order h for the installation

connected at LV, determined in accordance with procedure given in IEC/TR 61000-3-14 [48].

- The greatest 99 % probability daily value of individual harmonic components $U_{h,vs}$ (or $I_{h,vs}$), over "very short" 3 s periods, should not exceed the emission limit multiplied by the factor k_{hvs} given in equation:

$$k_{hvs} = 1.3 + \frac{0.7}{45}(h-5)$$

For flicker emissions, the indices are:

- The 95% probability weekly value of P_{st} should not exceed the emission limit E_{Psti}.
- The 99% probability weekly value of P_{st} should not exceed the emission limit E_{Psti} times a multiplying factor (for example: 1 - 1,5) to be specified by the system operator or owner, depending on the system and load characteristics;
- The 95% probability weekly value of P_{lt} should not exceed the emission limit E_{Plti}.

E_{Psti} (E_{Plti}) is the allowed flicker emission limit (indices P_{st} or P_{lt}) for the customer's installation directly supplied at LV, determined in accordance with the procedure given in IEC/TR 61000-3-14 [48].

For rapid voltage changes, because of their low frequency of occurrence, no statistical indices are considered. Thus maximum values of rapid voltage changes including frequency of occurrence should not exceed the emission limits.

An overview of the evaluation procedures for connecting disturbing loads to the low voltage power system, is included in IEC/TR 61000-3-14 report.

For disturbing installations (loads) that are to be connected at medium voltage, procedures similar to those in IEC/TR 61000-3-14 and described in:

- IEC/TR 61000-3-6: Electromagnetic compatibility (EMC) – Part 3-6: Limits – Assessment of emission limits for the connection of distorting installations to MV, HV and EHV power systems;
- IEC/TR 61000-3-7: Electromagnetic compatibility (EMC) - Part 3-7: Limits - Assessment of emission limits for the connection of fluctuating installations to MV, HV and EHV power systems, should be applied.

2.3.5.4 **EMC summary**

Standards regarding EV charging system in the area of EMC requirements are still at the stage of development. Where frequency below 2 kHz is involved, to comply with the requirements for measurement methods and conditions of performing tests and permissible emissions of harmonics and voltage fluctuations, respective references to basic EMC standards (IEC 61000-3-2, -3-3, -3-11 and -3-12) should be made. Such references should be complemented with additional necessary information on the EV charging system.

Vehicle chargers are classified as A-class equipment. It seems advisable to suggest a separate class for them within the IEC 61000-3-2 standard. This would allow for different charging modes (slow, fast AC, fast DC charging), particularly the fast charging mode, which

may generate increased disturbances to energy networks. It may be necessary to recommend various diagrams of reference networks depending on the charging mode.

Currently the limits of harmonics emissions regard only individual appliances as provided in IEC 61000-3-2 and IEC 61000-3-12. It does not refer to a potential situation when a large number of electric vehicles are charged simultaneously from the same supply network (which can be the reason for exceeding the EMC limits for power networks). This problem should be investigated.

Basic EMC standards do not contain any information on electric vehicle batteries used as energy storage to provide additional services for power networks. Chargers serving this purpose should provide for a two-way energy flow.

2.4 EV user behaviour patterns

The way of the EV utilization depends on many factors including technical (driving range, charging infrastructure or competing technologies), financial (purchasing and maintenance costs), demographic (gender, rural vs urban areas), geographic (climate, car parks availability), political (tax policy, subsidies) and even cultural ones. The latter categorization is complex and involves many different subcategories ranging from person-related aspects such as willingness to pay, environmental awareness, driving behaviour, personal perceptions etc. Moreover, significant differences between the refuelling of conventional cars and recharging of electric vehicles in terms of price, the process duration and available driving range, makes EV users behaviours difficult to predict. However, based on surveys carried out within EV related projects, it is possible to define several charging related EV using behaviour patterns.

The analysis presented below is based on surveys carried out within G4V and Green e-Mobility projects. The results refer to 8 countries (in G4V project) where the survey was carried out (United Kingdom, Germany, France, Spain, Italy, Denmark, Sweden and Portugal). Green e-Mobility project presents the results of survey performed in Ireland.

2.4.1 Description of surveys analysed

The survey carried out by G4V focuses on the following aspects: a minimum required driving range, preferences for parking and charging location, interest in delayed, vehicle to grid charging schemes, the role of price incentives and a leased battery. Due to categorization needs, respondents were also asked about their interest in EV, environmental awareness, currently owned cars, average driving distance, size of municipality they live in, age, gender and their current parking facilities.

The survey providers made the assumptions put together in Table 11:

Table 11. Assumption for the survey carried out within G4V

Assumption	Value
EV Availability	Market introduction phase, EVs

Assumption	Value
	available in the showroom
Average time needed to recharge the battery (normal charging, 120 km)	4 hours
Indicative battery capacity	120 km
Price for home recharging	€3
Price for public recharging	€5
Price for delayed (home) charging (22:00-6:00)	€2

Over 12 300 respondents participated in the survey. The total number of respondents by country is presented in the figure below.

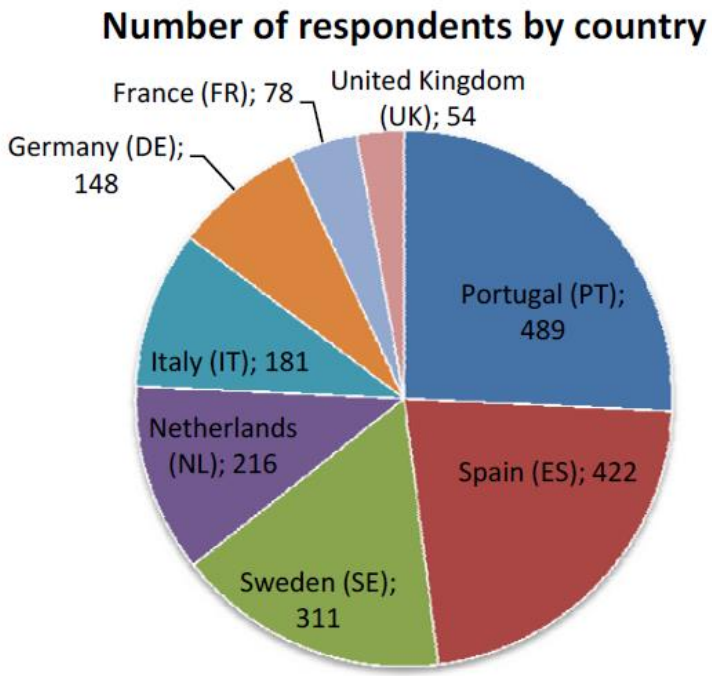


Figure 43. Number of respondents by country. [49]

As mentioned above, the respondents of G4V survey were asked about age and gender to define a potential group of EV users and make the research more authentic. The percentage of male and female respondents, also the structure of their age, are presented in Figure 44. Respondents by age and gender.

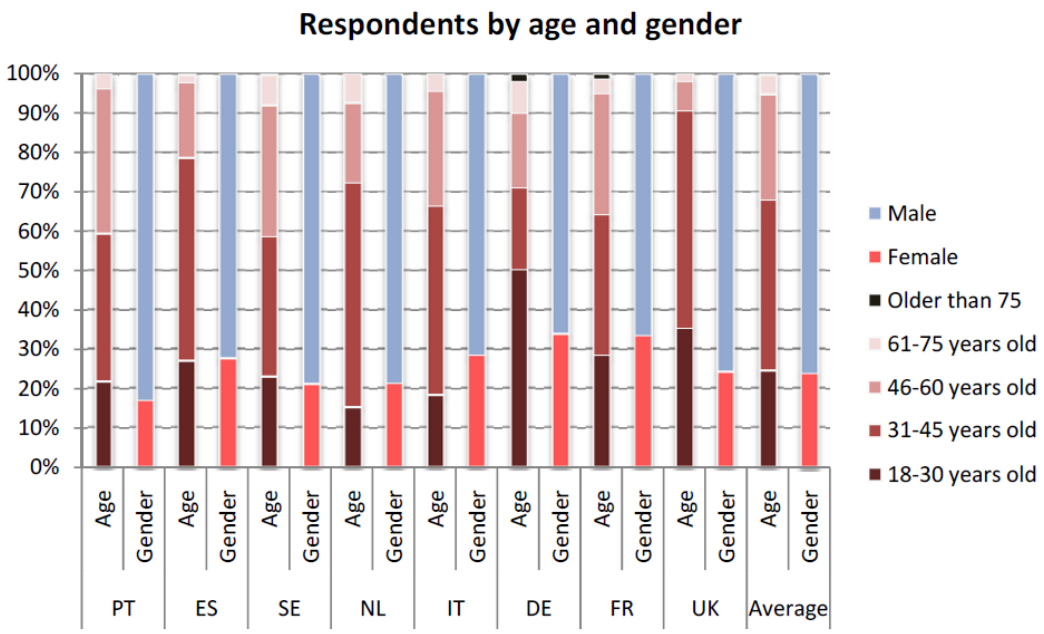


Figure 44. Respondents by age and gender [49]

2.4.2 Description of the analysed surveys results

In Europe there are 224 million passenger cars (data retrieved from G4V project referring to period between 2003 and 2008. In Germany, there are about 41 million cars, in Italy 36 million and 30 million in France and United Kingdom. However, the car density (counted as the number of cars divided by the population of each country) is highest in Italy and it is about 601 per 1000 inhabitants. About 500 cars per 1000 inhabitants are in Germany, Austria, Lithuania and Finland. The lowest density is in Turkey, Slovakia and Denmark (about 400). Currently, it is difficult to predict how the share of EV in total number of cars will change in the nearest future but these numbers show how serious problem with the network capacity there can be if the EV penetration achieves, let us say 80%. At first, problems may occur in the countries of the highest density, especially in Italy having the highest in Europe and where capacity is lower than demand (the electrical energy is transmitted by cross border connections from Austria and France across Switzerland) [49]. In addition to available capacity there are also aspects of power balancing, technical constraints of the grid etc.

The process of replacing conventional cars by EV also relates to the age of existing cars and citizens. The average age of cars in European roads is about 8 years. The oldest cars are in Lithuania where their average age is about 15 years. The 15 years old cars account for 34,5% of all of cars in EU. 31,9% of all cars is between 5 and 10 years. Most of them are in Germany, about 14 million. In Italy that number is lower by about 1 million (13 million) and in France it is about 10 million. The youngest cars are in the UK where average age is less than 7 years. The group of cars younger than 5 years represents about 33%. Most of the respondents inquired about whether they would like to have an EV answered that they considered the purchase of EV as a second car. The highest potential is in France where about 35% of society owns two vehicles.

One of important aspects is parking behaviour. It is especially important for electric cars due to the recharging process, which unlike gasoline or diesel refuelling, usually takes up to 8 hours (see subchapter 2.2.2). Even the solution with the shortest charging time – DC fast charging in 30 minutes - takes too much time to be performed during a travel. Therefore, the time when the car is left at a car park seems to be the best opportunity for batteries recharge.

Most of potential EV users live in medium sized towns (between 100 and 500 thousands of inhabitants). In response to the question where they would like to charge their EVs respondents' most common answer was that wherever they wanted. It shows how users' behaviour is strongly affected by long charging time span. 56% of 1621 answered that the most likely place to recharge their EV's batteries would be their own garage. The percentage grows when the question is about weekends. It is worth mentioning that 20% of respondents answered that they left their cars at work for the entire weekend. There were also a few respondents mentioning that they parked their cars in a street, shopping mall, car park and/or other public spaces.

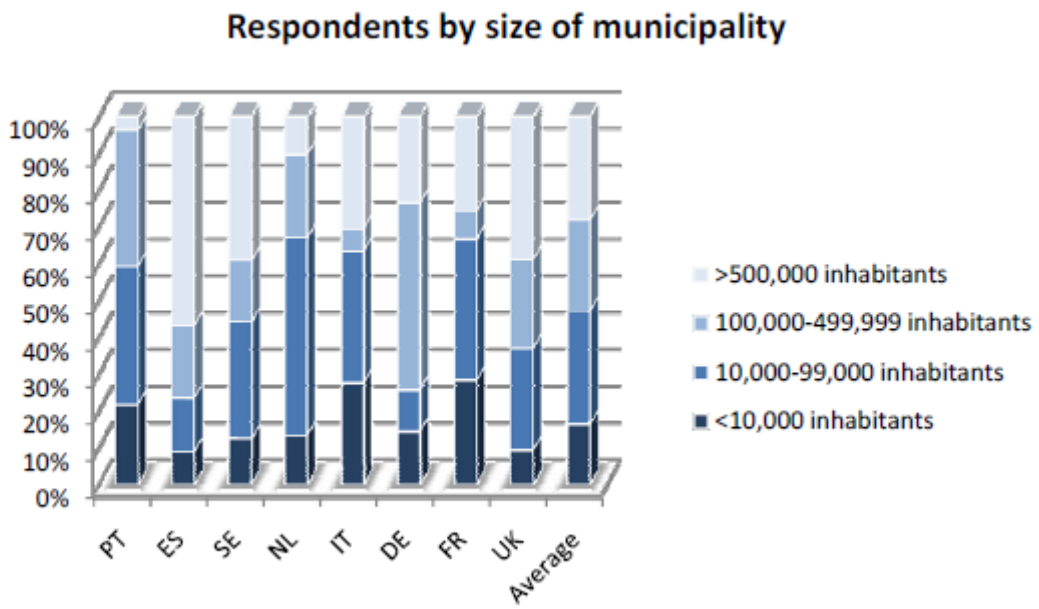


Figure 45. Overview of respondents by size of municipality [49]

The second essential aspect is a driving range available without recharging (see subchapter 2.2.2). The great majority of EV owners use their cars for commuting on a distance from 20 to 100 km (Figure 46). Longer distances regarding holiday or business travelling occurs relatively rare. Taking into account the available driving range and duration of charging process, travelling by EV is almost impossible if the distance exceeds 150 km (except for EVs which can be charged using 3rd and 4th mode). Therefore, it is justified to say that EV is a solution for commuting not traveling.

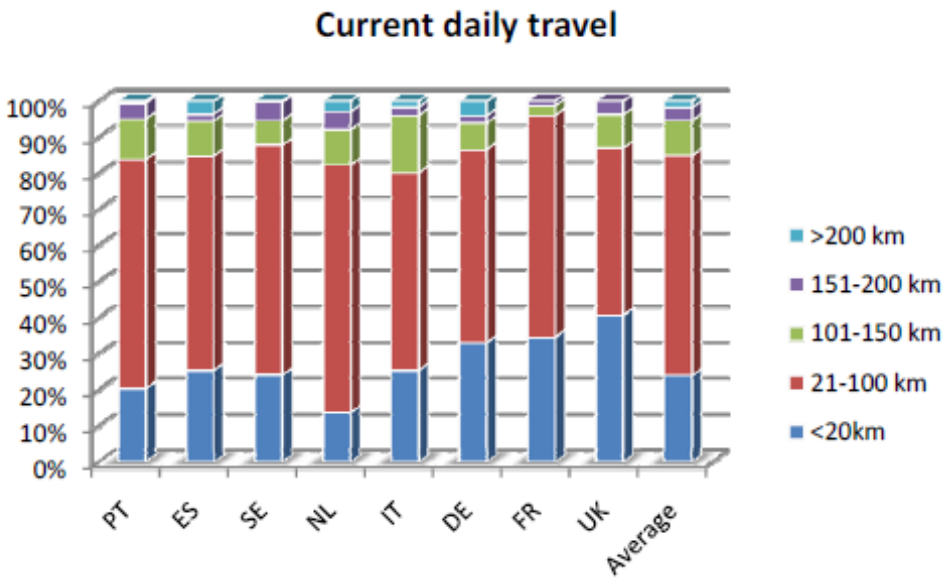


Figure 46. Overview of average daily traveling distances by country [49]

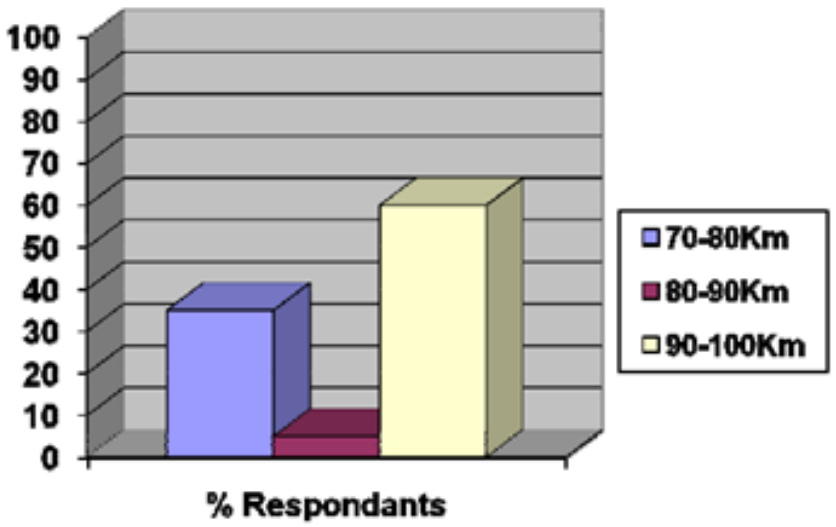


Figure 47. Overview of average daily traveling distances in Ireland [50]

Interestingly, respondents of Green eMobility answered that there were not any instances where they had to recharge their EV while using it away from head office during working hours. Moreover, when they were asked if they preferred a taxi instead of EV, the answer was also no. It shows that the available range is long enough for commuting despite the fact that it is much shorter than for cars with combustion engines.

Taking into account the average driving range, the driving distance and parking place availability, both public and private car parks seem to be proper places for charging. However, there is one more financial aspect which affects charging and user behaviour. Despite available infrastructure and life style, home charging is usually less expensive than charging at public places. Additionally, home charging allows for full recharge of batteries at night, when long time is available for the process. The DC fast chargers can provide only

partial recharge. Therefore, home charging should to be considered as the main charging spot.

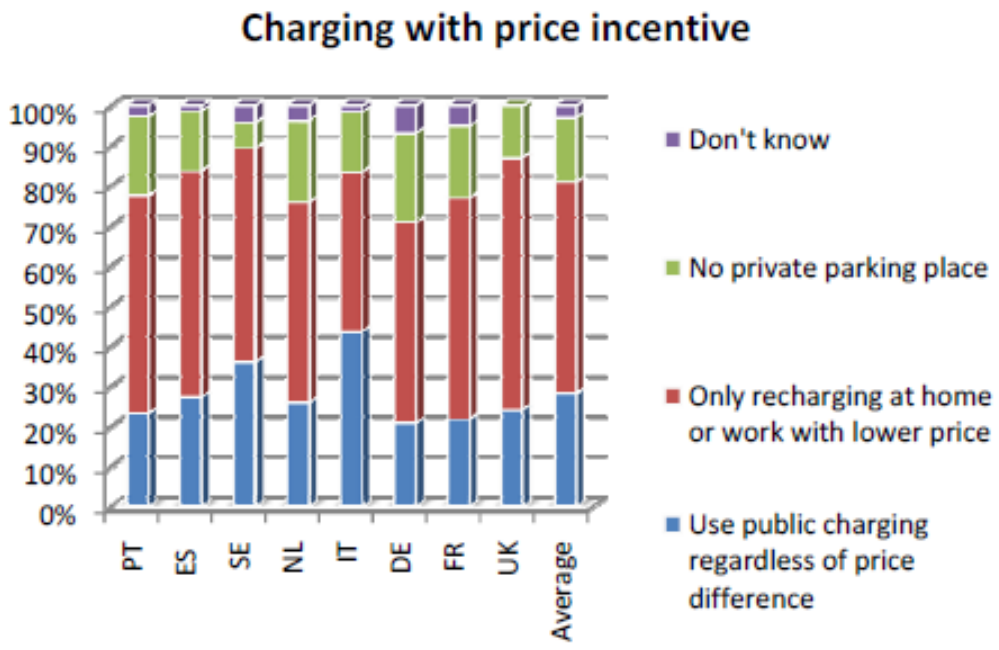


Figure 48. Overview of average daily travels distances by country [49]

At the end of the G4V survey, respondents were asked about their willingness to participate in V2G. Most enthusiastic about V2G are English and Portuguese; their summarized result was 4.94 and 4.58 respectively (from 1 – do not want provide V2G - to 7 very interest in V2G). The result was significantly lower in the remaining countries. One can also notice that there is a correlation between the age of a respondent and willingness to participate in V2G (those between 18 and 34 years old had nothing against V2G while respondents between 46 and 60 years of age found many reasons for V2G refusals). Figure 49 presents the structure of answers.

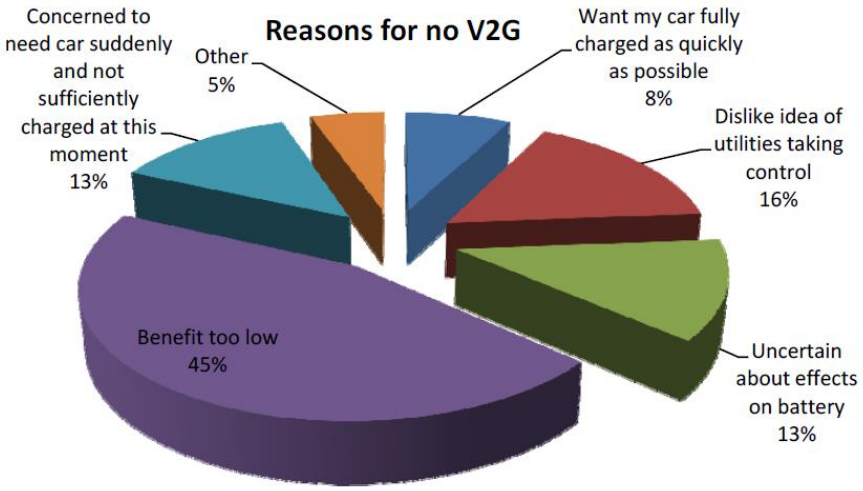


Figure 49. Reasons for not participating in V2G schemes and incentive [49]

Most answers such as “Benefit too low” or “Uncertain about effects on battery” are related to the concern about the battery condition and lifetime. Therefore, there was one more question about V2G:”would they be more interested in V2G, if batteries would be leased”. The answers show that it is not really the case. The structure of answers is presented in Figure 50.

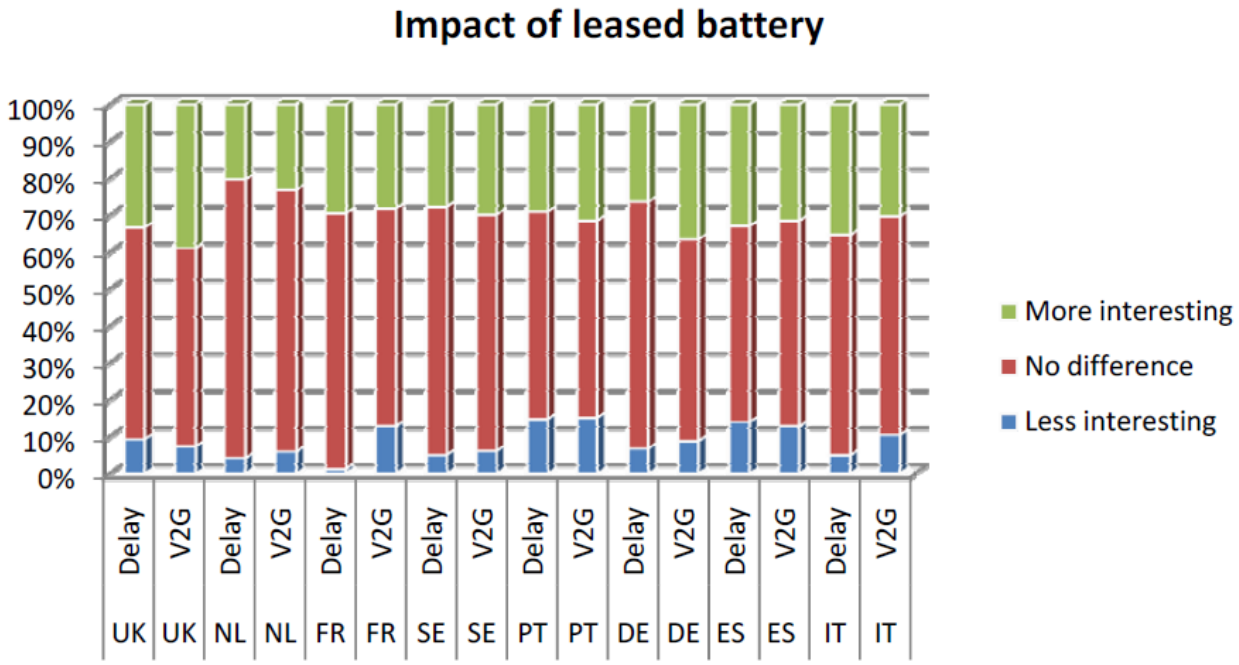


Figure 50. Interest of respondents in delayed charging and V2G schemes when batteries are leased instead of owned [49]

Considering the above described results three major EV user behaviour patterns can be defined:

1. commuting with home charging at night,

2. commuting with public partial recharging,
3. travelling with fast charging availability.

Patterns of private and fleet usage are assumed as the same as commuting utilization due to insignificant differences.

2.5 Functionalities

This subchapter summarizes different functionalities provided by EV and EVSE. The EV functionality is assessed mainly from the user's point of view with three main aspects being considered:

- safety and protection,
- charging procedure,
- communication between EV and EV user.

The consideration is limited to EV user behaviour patterns which according to previous subchapters are the most feasible:

1. User that utilizes EV mainly for commuting. Charging is performed at private parking place or public available access point **(AC slow charging).**
2. User that utilizes EV mainly for commuting. Charging is performed at public places (**AC fast charging**).
3. User that utilizes EV mainly for travelling. Charging is performed at public high power charging stations (**DC fast charging**).

2.5.1 Safety and protection

From the EV user's perspective safety relates to the process of charging. The most important issues are:

- user protection against electric shock,
- verification and adjustment of charging parameters (e.g.: voltage, current),
- prevent connector from being energized before its connection to the vehicle,
- prevent vehicle from driving off while connected to a charging device.

To achieve these safety goals, the EVSE provides several functionalities on which the EV is required to respond. For example, the control pilot function of the EVSE monitors the circuit between its control pilot (CP) and the protective ground PE, which is conducted via the EV. The function is obligatory in modes 2, 3 and 4. In case of mode 1, the function does not exist. If the circuit is opened, the charging station will not power the plug. If the circuit is closed, the EVSE can determine the presence of the EV as well as the permitted current rating. In addition, the EVSE can check the protective earth continuity. On the EV side the detection of the control pilot signal will deactivate the driving function. To further improve safety, a locking mechanism is used to prevent disconnection of the plug from the outlet under load.

According to [13], the control and proximity pilot:

- Verifies that the vehicle is present and correctly connected. The system should be able to determine that the connector is properly inserted in the vehicle inlet and charging station.
- Permits energization/de-energization of the connector. Energization is possible only when the pilot function between EV and charging station is correctly established.
- Prevents the car from driving away during the charging process - the EV propulsion system should be deactivated while physically connected to EVSE.
- Transmits current rating to the vehicle,
- Continuously monitors the presence of the equipment ground.

In case the EVSE has to provide power to several EVs at the same time, an integrated de-rating function will control the power distribution to the outlets, avoiding thereby stressing the power electronics of the EVSE.

2.5.2 Charging procedure

The issues that are considered in this subchapter relate to the charging process provided by EVSE to the EV and are in the following domains:

- compatibility of connections between EV and EVSE,
- charging procedure.

For the charging modes described in subchapter 2.1.3 different inlet and connector standards have emerged worldwide recently. Thus the compatibility issue is present in every charging case previously mentioned. To ensure interoperability the EVSE can provide several plugs to charge the EV. As in Figure 28, the DC charging station (mode 4) may be equipped with both CHAdeMO and CCS connectors. In other scenarios the EV user may require the usage of additional AC adapters.

For slow AC charging the EV is connected to the grid via a regular socket/outlet or dedicated wall box for a time span of about 8 to 10 hours (needed to charge battery fully). The public charging stations of higher power rating offer quick charging capabilities and the time to get a partially or fully charged battery can be reduced to a few hours. In case the EVSE provides a DC rapid charging functionality, the battery can be brought up to 80% of its state of charge in less than 30 minutes. The connectors applicable for such high power ratings are provided by the above mentioned CHAdeMO and Combo2 standards. Currently, in Europe, car manufactures equip their EVs primary with the Combo2 plugin which allows AC and DC charging.

The AC charging procedure is similar for all three modes but can be provided by different appliances. In mode 1 and mode 2 the on-board charger controls the charging procedure. In mode 2 user safety is improved, hence a cord-set should include the RCD protection device. There is a significant difference in mode 3 where the charging station might have versatile communication, service and billing functionalities (see subchapters 2.1.3 and 2.3.3). In mode 3 the information about the state of charge and batteries condition (temperature etc.) is collected by on-board unit and transmitted to the EVSE where charging parameters are set. When the battery condition changes, the EVSE updates charging parameters. In case of DC charging (mode 4) the charging process is carried out in the same

way, however the rectifier is located off-board and requires continuous communication with the vehicle's BMS system.

In conclusion, contemporary charging procedures may be followed in many ways and are determined by the charging equipment of EV and EVSE. There are several standardized types of connectors, power converters and charging stations allowing for charging in one of four modes. Since most currently available EVs and EVSEs may use different charging modes, thus it becomes easier to find a suitable charging point for any type of EV. In Europe Combo2 standard is most promising connector and plugin solution. It allows for both AC slow and DC fast charging.

2.5.3 Communication between EV and EV user

Communication between the EV and EV user will be required to enable/facilitate the charging process and includes:

- user identification and payment service,
- EV user services.

The payment service is determined by the payment method. There are plenty of payment methods but there are two main categories which can be distinguished: instant payment and periodic contract. The first one refers to occasional charging while the second one applies to EV users which entered the contract with EVSP for regular charging.

For the user authentication and authorisation on the EVSE the most common identification method is by ID card information from Radio Frequency Identification (RFID) cards. The data such as prices, payment methods, charging parameters etc. are provided from the system operator via the EVSE to the EV user. In case the EV user has forgotten or lost RFID card, there are other means to gain an access to the EVSE. For instance, by SMS message (requires initial registration of the mobile phone number), containing the charging station number, to the Charge Point Management System (CPMS) that would trigger the start of a charging session.

At each start of the charging session detailed information such as transaction ID, token ID, start timestamp and kWh register is recorded and periodically updated as the session progresses with timestamps and point in time readings from the corresponding meter kWh register. With this, transaction recoveries following any system failure can be handled as if the charging session had just completed at the time of the last recorded timestamp. Furthermore, this ensures a fair billing of the customer. The recorded data are transmitted to the Charge Point Management System (CPMS) using a client-server methodology with the CPMS primarily functioning in the server role and the managed charging stations functioning as clients.

Most vehicle manufacturers provide smart phone apps to remotely monitor and control the EV. Renault calls their app Z.E. Services. The app Volkswagen provides is called Car-Net. This app displays the location of the vehicle and provides information about the current state-of-charge, hence, the resulting remaining driving distance and in case of charging the remaining charging time as well as the passenger compartment temperature. Next to these

monitoring functions, the user is able to start, stop or schedule a charging process as well as precondition the passenger compartment temperature.

The main functionalities provided by EV and EVSE commonly used today are presented in Table 12. The more advanced functions/services allowing e.g. for the definition of charging profile are discussed in Chapter 4.

Table 12. Summary of functionalities provided by EV and EVSE (n/a - non applicable)

		SAFETY				CHARGING						COMMUNICATION		
		User protection against electric shock	verification and adjustment of charging parameters	preventing connector	prevent vehicle movement	Compatibility connector					Charging power rating	verification and authorisation	charging parameters	payment services
						TYPE 1	TYPE 2	TYPE 3	COMBO 2	CHADEMO				
SLOW CHARGING	MODE 1	X	n/a	X	X	X	X	X	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 2/ 1-phase	X	n/a	X	X	X	X	X	X	X	n/a	X	n/a	n/a
	MODE 2/ 3-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 3/ 1-phase	X	X	X	X	X	X	X	X	n/a	n/a	X	X	n/a
	MODE 3/ 3-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
FAST AC CHARGIN	MODE 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 2/ 1-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 2/ 3-phase	X	X	X	X	X	X	X	X		X	X	X	X
	MODE 3/ 1-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 3/ 3-phase	X	X	X	X	X	X	X	X	n/a	X	X	X	X
	MODE 4	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

		SAFETY				CHARGING						COMMUNICATION		
		User protection against electric shock	verification and adjustment of charging parameters	preventing connector	prevent vehicle movement	Compatibility connector					Charging power rating	verification and authorisation	charging parameters	payment services
						TYPE 1	TYPE 2	TYPE 3	COMBO 2	CHADEMO				
FAST DC CHARGING	MODE 1	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 2/ 1-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 2/ 3-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 3/ 1-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 3/ 3-phase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
	MODE 4	X	X	X	X	n/a	n/a	n/a	X	X	X	X	X	X

2.6 Summary

The major disadvantage of currently used Li-ion batteries is low capacity per 1kg of weigh. Li-air batteries could be good alternative, which capacity is 20 times larger, but the technology is not ready for mass production yet. Another disadvantage of Li-ion batteries is significant dependence of recharging cycles from charging method. Charging duration can be shortened by usage of high power charging but it can reduce the battery lifetime. Low power, single-phase chargers are the most commonly mounted in EVs, unlikely to expensive high power chargers. However, in future, EVs should be equipped with bi-directional chargers, which are essential for V2G.

BMS system ensures proper charging procedure, which allows for maintaining battery good condition. Information about state of charge for battery is presented by HMI. The interface also allows for programming of charging cycles.

The range of EV can be extended by range extender systems. This issue does not directly influence the interoperability, but increases the possible vehicle range of use and reduces the so called “range anxiety” for potential users.

EV connects with the grid via dedicated connector. Introduction of guidelines for usage of COMBO2 standard allows for unification of connectors and inlets within the EU. The standard can be used for CCS (Combined Charging System) for charging with direct and alternating current according to user’s need. The functionalities of EVSE are extended by introduction of new services such as charging spot booking.

The LV networks typical for the urban area, are able to accommodate the largest number of EVs without negative results for the power system. Single feed networks, typical in the rural areas, may need some reinforcement to integrate EVs in higher quantities than today. Security of supply, due to the network configuration differences, is much lower in rural area than urban one. This results in some kind of risk, that EV user, living outside the city/town will not be able to reach the work, due to the discharged EV battery.

Power consumption profiles indicate that the best option for the grid operator is to charge EVs during off-peak hours at night and to utilize EV batteries as energy source during peak demand. For DSO EVs with EVSE can represent a tool for the grid management. There is a correlation between the concepts of e-mobility and smart metering, therefore an effect of synergy of the both arises. From the DSO point of view, the online access to information on the LV level is the precondition for further integration of EV charging services, including V2G and Smart Charging.

According to the EMC aspects, following postulates can be formulated:

- Appendix: C of the IEC 61000-3-2 and A of the IEC 61000-3-3 should be extended by conditions of test type of EV chargers. Those conditions should include at least the following information: examination time (i.e. full charging cycle) and operation status (for which the test is carried out).
- Potentially high number of simultaneously charged EVs may lead to EMC standards violations. Thus the DSO should be able to limits the number of charger connected to the network. The issue should be investigated.

- EMC standards do not include cases of bi-directional chargers usage for V2G provision. Those cases should be investigated.

The EV functionality is assessed mainly from the user's point of view with three main aspects being considered:

- safety and protection,
- charging procedure,
- communication between EV and EV user.

The consideration is limited to EV user behaviour patterns which according to previous subchapters are the most feasible:

- User that utilizes EV mainly for commuting. Charging is performed at private parking place or public available access point (AC slow charging).
- User that utilizes EV mainly for commuting. Charging is performed at public places (AC fast charging).
- User that utilizes EV mainly for travelling. Charging is performed at public high power charging stations (DC fast charging).

Above listed limitations, resulting from user behaviour patterns, introduce another charging station classification. It is defined regarding from its localization and accessibility for users. Depending from the category (private, charging etc.) the station have different influence on charging strategy. The chapter "Conservative Word" describes three types of charging stations private station, captive station and public station, indicating on its localization, functionality and accessibility.

3 ELECTRIC MOBILITY FUTURE SCENARIOS AND THE POTENTIAL FOR THE INFRASTRUCTURE (GRID)

3.1 Introduction

Given the energy and climate goals set by the European Union in 2009, electricity generation is to change drastically [51]. Renewable energy sources (RES) will become a significant part of the EU electricity generation mix. Moreover, the European electricity industry has set itself the challenging objective of achieving a carbon-neutral power supply by 2050.

Changing sources for generating electricity affect the transmission and distribution of electricity. RES differ significantly from conventional electricity sources due to their volatility, which causes production peaks and valleys in the electricity grid. Presuming a steady growth of the EV population and presuming straight forward plug-and-charge scenarios, the electricity grid will be out of balance even more as the EV electricity demand will typically peak around 19:00. Demand-side responsiveness of EV chargers and possibly even bi-directional communication between EV and charging spots is presumed to be needed to tune the electricity demand and make the best use of the available electricity. This bi-directional communication enables controlled charging procedures: the vehicle will be charged “off peak” using the available grid capacity. Smart charging therefore not only enables optimal use of RES capacity, but is also indispensable to avoid additional demand for (non-RES) electricity, which in turn requires additional generation capacity, especially during peak times. Indeed, electric vehicle applications could be used as an enabler for future bi-directional communication in the electricity grid (smart grid) which will be key in future smart city concepts.

Smart charging refers to a controlled charging process that optimizes the use of the grid and the available electrical energy to minimize additional investments in the grid and facilitate the integration of RES. Such control mechanism shall be supported by the grid, by the charging point, and by the vehicle itself, while a communication system with the grid allows the charging process to take actual grid capabilities into account. Price or control signals can be communicated through an information and communications technology (ICT) infrastructure in order to allow intelligent charging algorithms to take into consideration generation and grid constraints and to allow the consumer to benefit from price opportunities. Smart charging should respect the customer's needs and charging requirements regarding vehicle availability as long as there are no critical limitations by the grid or the energy supply.

Coordinating and managing the loads will:

- facilitate the integration of RESs into the electricity system, especially with regard to decentralised generation connected to the distribution grid;
- enable grid management that introduces flexibility into the system;
- ensure a cost-effective solution;
- optimise an efficient charging process taking into account generation capacity;
- maximise consumer convenience through user-friendliness.

3.2 Market development

The discussion so far has focused on the integration of EVs into the electricity grid under mass market conditions. However early EV market introduction will take time: until 2020 the feasible market share of EVs is expected to lie below 5-10% [6]. Under these circumstances, controlling and managing the charging patterns of EVs and other loads can be ensured with today's existing technologies. For instance, off-peak price signals and programmed charging will contribute to a load-efficient charging process of electric vehicles based on RES as well CO_2 free operations.

However, these basic measures might not be sufficient under mass market conditions, especially given increased electrification of applications (amongst others heating and cooling) due to more energy-efficient systems such as heat pumps. In a second step – beyond 2020 – a mass market share of EVs will therefore require an intelligent connection between EVs and the electricity distribution grid, thereby ensuring their optimised integration and security of supply for all customers under mass volume conditions.

Connecting a mass market share of EVs to the electricity grid can expose the grid to a dramatic increase in maximum power demand. In that case heavy investments will be required with regard to reinforcing the cables between households and transformers, the transformers themselves as well as investments in the upstream grid. Such consequences can, in general, be minimised by coordinating the additional loads, i.e. by smart charging, thereby avoiding additional costly or at least non-profitable investments in the grid through a better smoothing of the load curve. Due to long lead times, an 'intelligent connection' and the required standards need to be developed now.

The idea to use electric vehicles as distributed energy storage units (called Vehicle-To-Grid or V2G) has been widely discussed in the past years. There are a lot of different scenarios and use cases that have been considered. However, the integration of EVs into the electrical grid is a complex task. The connection of an EV to a smart home system (also called Vehicle-To-Building (V2B), or vehicle-To-Home (V2H) could be considered as an intermediate step. An important prerequisite for both scenarios is some kind of communication link between the vehicle and a control instance on the grid side. Other task to be deeper investigated refers to rechargeable energy storage system (REESS) increased energy throughput, i.e. battery lifetime reduction or battery cost increasing.

3.3 Scenarios and EV control strategies

There are several future e-mobility scenarios, which have different impact on the grid operator, market participants and the general charging control strategies.

We can assume that EV is an inflexible load that needs to be accommodated by the system at any cost. The integration of physically connected EVs into the grid, however, can be seen from a different perspective given that each connected EV is a load with electric energy storage capacity. Moreover, transport studies have shown that the EV passenger cars are likely to stay connected to the network idle for large periods of time and that in the majority of cases the total energy of the battery is not spent in the average daily journeys. To be also taken into account is that electric commercial vehicles and electric busses are likely to stay connected to the network idle overnight and that in the majority of cases most of the

battery energy is spent during daily journeys. That said, if the EV is not regarded as an inflexible load, and the full potential of natural distributed storage nature is explored, then they can change from being a problem to become a solution to support system operation as a source of flexibility. This, however, requires that adequate system operation practices are put in place to unlock this flexibility.

Control strategies are dependent on the information flow, which is a precondition for any kind of charging/grid management. Different control strategies reflect different development scenarios.

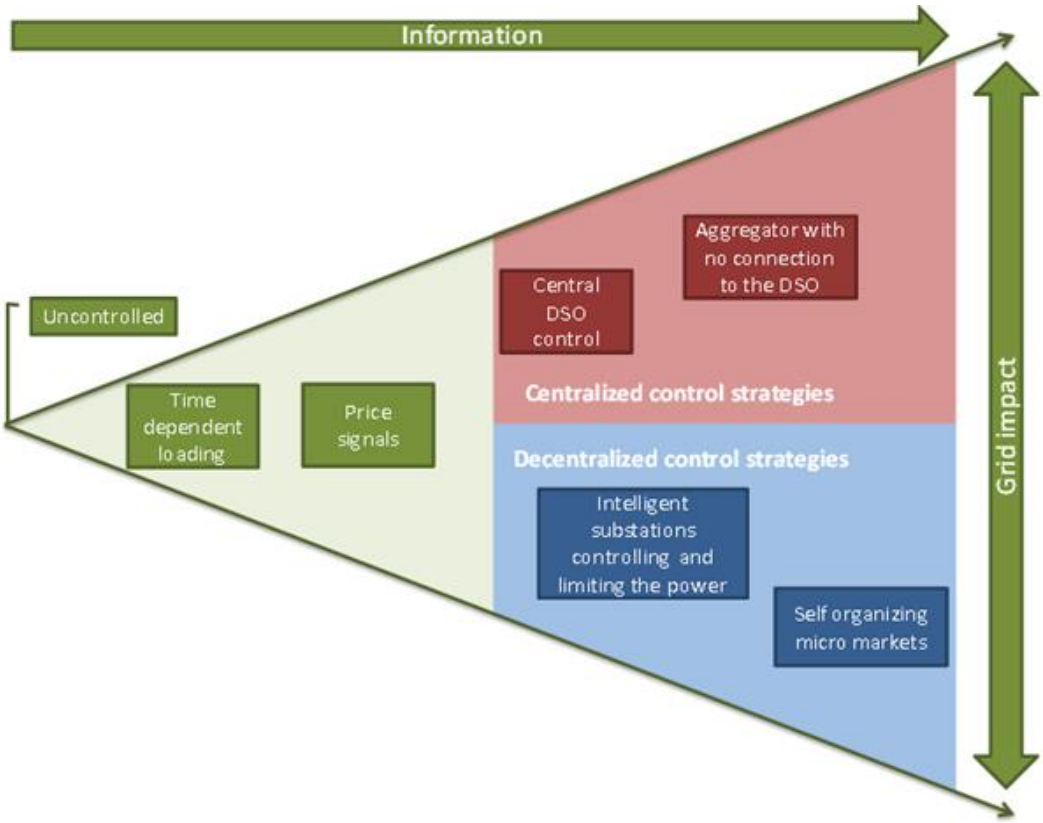


Figure 51. Evolution of control schemes [52]

Based on the G4V project definition, we distinguish 3 possible scenarios for the control strategy definition:

I. Conservative world
II. Pragmatic world
III. Advanced world

These scenarios will be sections that follow.

3.3.1 Conservative world – non controlled infrastructure

For the conservative world, the control strategies are simple, needing no communication or very simple unidirectional communication (for time of use (ToU) tariffs for instance). These solutions are already being used today or can be put in place with existing technologies.

The conservative world pursues a business as usual approach. In this scenario the grid planning and control is organized as today and the recharging infrastructure is not controlled. Smart meters are installed but have a very limited functionality.

Private stations

A private station is a recharging infrastructure for use in private parking places (garage), therefore charging does not require customer identification and the infrastructure does not require additional features beyond safety requirements. Other functionalities and requirements shall be considered optional to provide added value services, such as a display to inform the user about the state of the charge.

Captive stations (EV fleet owners) stations

A captive station is a recharging infrastructure for use in captive/company/municipality/car rental parking places (depot), with access allowed to more persons, but as these persons are affiliated with the same company/organisation complex customer identification (as for public stations) will not be required and this infrastructure also doesn't require additional features beyond safety requirements for public charging, such as cost and functionality optimization, fleet management and related added value services.

Public stations

A public station is a recharging infrastructure for use in streets, public parking areas, public garages and other places with access allowed to more (non-affiliated) persons; therefore the access to the infrastructure should be restricted to the authorized users (i.e. clients of the charge service). This limitation is needed in order to enforce safety and security and in order to allow billing of the clients. In order to control the access to the service, it is needed to establish an authorization process that every client has to undertake before the charging service could start. Such an authorization can be provided using a number of different solutions:

- Pure mechanical (key): this method is very simple to implement and it has been used in a few pilot projects. Nevertheless, it is suitable only when the number of customers is very low. This is not a preferred solution nowadays.
- User interface: the user can be required to use a user interface on the charge infrastructure to insert a code (e.g. a pin) in order to identify him/herself. Typically stations without remote connection are using this interface for customer access.
- Smart card: this system requires the use of a smart card which stores some kind of user identification. The stored information can be a simple identifier (i.e. a unique contract id) or can also contain additional information, such as a credit for pre-paid contract. The use of the card can be combined with the user interface (e.g. to enter a PIN code)
- Communication between the vehicle and the infrastructure: similar to smart card solution, but the information is stored inside the vehicle (and communicated e.g. via IEC 15118)

- Payment card: in this case the user can directly identify and authenticate him/herself and pay using a payment card also without having a contract (micro-payments are becoming an accepted way of payment for small amounts).

An appropriate user interface, such as a local display, is required to communicate the outcome of the authorization. In addition it can be used to easily provide information about the recharging in progress: times, costs and other optional data such as CO_2 not emitted and energy saving in comparison to use a traditional car with ICE.

The authentication and authorization procedure can be managed completely by the charging station itself, or can be delegated to an external system which contains the database of users and contracts. This depends on the market model selected in every country.

It is advisable to have a remote authorization system (single or distributed) and provide the charging station with a communication channel. The same communication channel toward an EVSEO Control System could be used to transmit data needed to bill the clients for the use of the infrastructure. Without such a mechanism, the same data should be collected directly from charging stations implying high labour costs and delayed billing. In addition, the communication with a Control System can be used in order to control the charging station by sending commands to it. For example it could be possible:

- to open and close the switch on the station
- to lock and unlock the sockets,
- to stop and restart the charge

Those functionalities are particularly useful to handle remotely contingency situations. For example a customer who has lost his smart card can call a help desk in order to regain access to the infrastructure. Finally, a communication channel would allow the charging station to communicate to a control system also information about the delivered quality of service and in particular possible interruption of the charging process (with date and hour of interruption), malfunction and attempt of tampering.

In the conservative scenario, where the charging infrastructure has limited communication possibilities, if any, the network operator does not have enough information about the actual grid status. For the efficient grid management at all levels, the information access is the precondition, because it allows the interaction between the grid, and local generation (among them RES production) and loads (among them EV charging) in a way that it limits loading peaks and necessary additional grid investments. Without the information access and management of the charging sessions the combination of the RES production and non-managed EV charging can lead to congestion in the network even if the share of EVs remains low. This scenario does not support the efficient spread of EVs, because it does not develop all electric mobility aspects properly.

3.3.2 Pragmatic and Advanced World – controlled infrastructure

For the Pragmatic World, relatively simple solutions, using unidirectional or bidirectional communication are proposed. These consider only unidirectional energy flows (no V2G is considered) and the main goal of this is to minimize the impact of electric mobility on the electricity grids (regarding production and distribution).

Controlled infrastructure applies to both Pragmatic World and Advanced World and allows an external actor to remotely control in real time the charging process. This requirement implies that the charging stations are provided with a communication device able to receive with low latency requests from a Control Centre (centralized or distributed) potentially during the entire charge process. Nevertheless, different levels of service are applicable to the two different scenarios:

- Pragmatic World: charging stations are controlled by the DSO (via EVSE Operator) which can send signals to reduce charging power when congestions are detected in distribution grid. The minimal requirement is to have a mono-directional broadcast real time communication (e.g. containing a dynamic electricity pricing forecast), although more advanced mechanism (bidirectional) can improve DSO capability to analyse in real time the response of the control actions.
- Advanced World: charging stations cooperate with the actors responsible for providing the aggregated function of grid stabilization or cost minimization. In this case, multiple subjects can play this role, hence bidirectional communication is envisaged, because the different players shall know the amount of customers able to participate in the aggregated service.

In the Pragmatic World, the control strategies are intended to add some additional features to the BAU (Business As Usual) strategies without a need for significant advances in terms of technology or system and network operation practices. The control strategies consider actions to shift EV charging demands or to reduce the charging power in order to reduce local congestion and alleviate substation overloads. More advanced services such as V2G (EV discharging energy to the grid) are not considered.

In the Advanced World, two main approaches were developed [53]. The first one is based on the concept of aggregation and is analysed by simulations for the system level without considering network constraints. It is however explained that network constraints and coordination with the TSO/DSO can be added to the same strategy. The second one uses largely the principle of decentralized intelligence, with local market agents and local marginal prices to manage network congestion.

In the Advanced World it is assumed that advanced ICT infrastructure is available and that significant changes in terms of regulation and market design, when compared to the ones of today, can be envisaged so that the demand side can take an active role in the operation of the power system.

Under this environment more advanced control strategies for the integration of EVs can be developed. In these strategies the EV is seen both as a flexible load and distributed storage device that can interact with the system both as consumers and producers (in V2G mode). The EV becomes an active player in the system that, on the one hand, uses electric energy for motion and, on the other hand, trades its charge/discharge flexibility with the objective of making economic benefit.

The first approach is based on the aggregation of EV flexibility to offer larger volumes of flexibility into different markets to maximise the profit of the flexibility services offered whilst ensuring the EV primordial role – mobility. The second approach is based on the existence of a fully distributed market where (the owners of) individual EVs become market players and optimise their charge/discharge in real-time in response to local real-time price signals. Also in this case, the primordial role of the EV – mobility – is kept and only the remaining flexibility

is considered available for trading. Both these options are based on the knowledge that mobility studies have shown that in general passengers cars are idle 90% of the time leaving a significant margin for using its battery for services other than mobility.

Evolution of control schemes is dependent on how the market will mature. If there will be simple market structure in place, rather uncontrolled charging is foreseen. Once the market structure will include different roles or various participants (EVSE, EVSP, EVSEO, aggregator, DSO/flexible demand management, etc.), control schemes will be based more on the bidirectional information flow. Then the control mechanism will split into levels – local and remote SECC (Supply Equipment Communication Controller). Local level is the level of a household or an office building; remote level is the level of the electric grid (substation).

Table 13. Comparison of three frameworks for the strategy definition [53]

	Conservative World	Pragmatic World	Advanced World
Charging control	No	Yes, simple charging control	Yes, complex charging control
Prices	As today	Dynamic tariffs	No limitation
Regulation	Conservative	Some liberalization	Optimal situation for EVs
Services	Unidirectional, no services	Unidirectional, all services can be provided	Bidirectional, all services can be provided
Grid infrastructure	Conventional development	Smart grids	Advanced smart grids, virtual power plant etc.

In addition, using the communication device for implementing the charging strategies, it can be used to provide all the functionalities provided in previous section:

- Authorization: when the user requests to access the infrastructure, the request can be forwarded to a remote central system where users/contracts database is stored.
- Remote Operations & Maintenance: having a direct communication to back office systems, it is possible to remotely monitor the infrastructure in order to detect immediately fault conditions. Moreover, it is possible to remotely configure the operational parameters of infrastructure and update its software
- Billing: after the charging process has completed, it is possible to send metering data and other parameters of charging session to the central system in order to bill the client.
- Roaming: national and international roaming granting access to all customers of all EVSE operators.

a. Private

In the controlled private infrastructure, the additional resources (communication channel and control unit) are mandatory in order to provide the control of charge process. Therefore it is a logical step to extend their use also to support additional functionalities, as described before. Privately controlled charging (V2H, V2B) is a likely candidate for integration with the SmartHome applications, where there it is necessary to leverage the power demand on local level.

b. Public/captive

The controlled public infrastructure shall provide the combination of all the already described features; therefore it is the most complete one. In any case, the additional costs are not expected to be far higher compared to other solutions, because most of the equipment is shared by different functionalities.

3.4 Scenarios and generic use cases

Scenarios and control strategies are in close interaction with generic use cases applicable to electric vehicles:

- Only recharge possibility: This category gives only the possibility for connecting the EV to the grid at different home and private locations. The aim is to recharge at any available location where necessary. Low power is foreseen. No charge load control from EVSE is foreseen. For further information, refer to IEC 61851-1 mode 1 and mode 2 (see Chapter 2). [25]
- With EV demand response with price signals: This category gives the possibility to connect the EV recharge at any place where a demand response capable EVSE is installed. The extra communication makes it possible to receive price signals or other incentives so that the end-user's reaction is possible. This gives the possibility for demand response in the same way as for other loads connected to the grid refer to IEC 61851-1 mode 3 and mode 4 (see Chapter 2).
- With unidirectional smart recharge (e.g. via a mobility service provider): The smart recharging provides a more controlled way of EV charging. This opens a way of smart charging and even V(end-user)2G possibilities based on flexible contracts and technical signals for charge load control, i.e. recharging time, timetable, power and cost. For further information on load control, refer to IEC 61851-1 mode 3 and mode 4 (see Chapter 2).
- New (mobile) billing systems: This category describes possible mobile billing systems like Radio-Frequency Identification (RFID), Mobile Phone, credit card and others.
- EV charge infrastructure management system: This category describes the complete system necessary for intelligent charge equipment management, including identification, status reports, malfunction management, etc.

3.5 Smart charging

For the sound development of the e-mobility concept the managed charging is the right way. Managed charging is possible in the pragmatic and advanced scenarios and concerns both the private and public/captive charging. Smart charging offers the maximal advantage of charging from the grid perspective.

From an electricity grid perspective, an EV can be seen as a highly distributed flexible load and electricity storage device, which may be used for supporting system operation. The EV can have both positive and negative impacts in the power system. If adequate strategies for the integration of EV are put in place, the negative impacts may be partly or even totally

mitigated and the positive impacts can be maximized and made available to support the system.

Depending on the exact placement of the electricity demand (as a function of time) imposed by the EV population, this new load can have an important impact on the system, given that if it coincides with the existing peak demand it will reduce the margins to the operational limits that the system currently has. In the case of systems that are currently operated close to their limits already a small population of EVs can lead to overloads in different parts of the system and will create a need for new investments.

The graphical analysis, presented in Figure 52 depicts the time spread of charging power throughout a course of one representative week day assuming uncontrolled charging and a large population (higher diversity factor) [52].

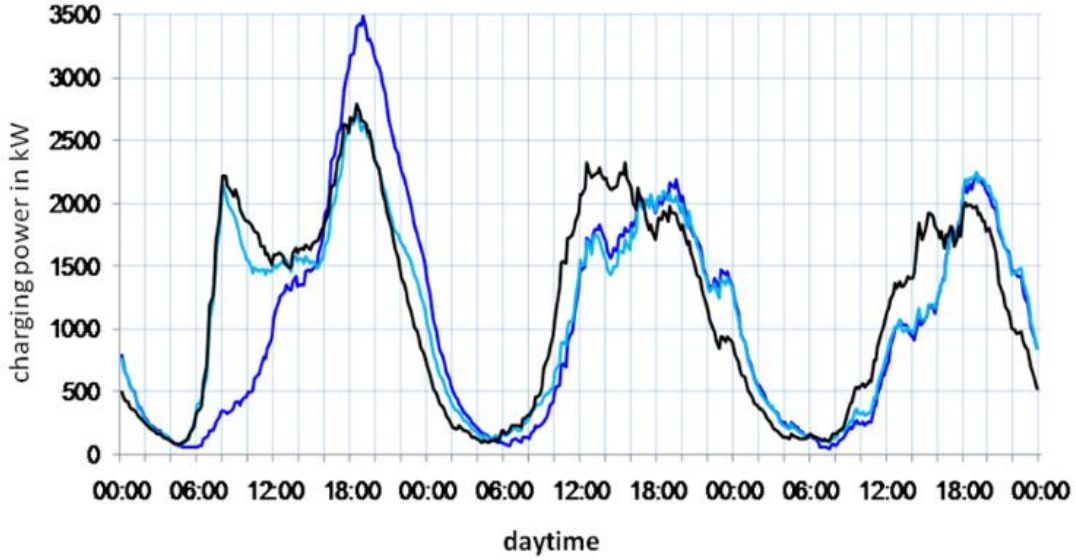


Figure 52. Spread of charging power in an uncontrolled charging environment

For the smart charging functionality a Load Balancing Controller (LBC) is an important component. It is the module responsible for scheduling and controlling charging sessions according to charging priorities, prognosis of demand relevant to EVs, restrictions imposed by the vehicle, the grid and the charging infrastructure, so as to manage the EV demand and prevent grid voltage deviations and equipment overloads

[52]. The LBC could be implemented over any type of distribution control centre, but its exact location may be only determined according to a European regulation or according to the market trends. Therefore LBC will be operated at the low power transformer station by an entity, which will be aware of the grid power restrictions and will be responsible for the grid stability and the scheduling of the EVs charging. This attitude offers a variety of market models reflecting the EURELECTRIC analysis.

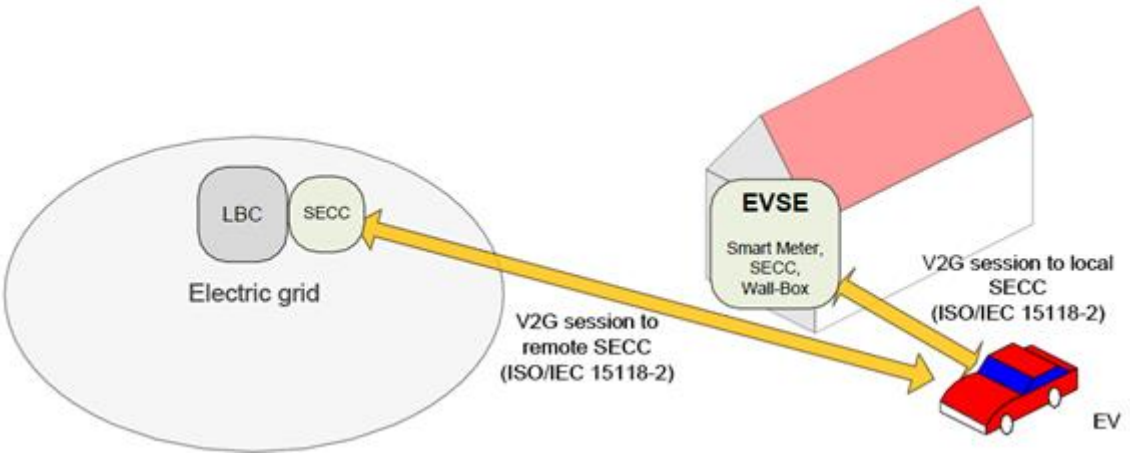


Figure 53. Architecture for charging controlled by V2G protocol only

The LBC and local Supply Equipment Communication Controller (SECC) will provide their own restrictions to the other involved entities according to the architecture described previously, and a decision will be taken by the EV on the power level to be delivered to the EV, considering the minimum of the following three values: the maximum power requested by the EV for its REESS (batteries), the maximum power supported by the grid and the maximum power supported by the charging infrastructure [105].

Beside the grid management tools, tariffs are another way of influencing the charging behaviour. The following definitions of types of tariffs are used:

1. Constant Price - a contract with a constant tariff throughout the day and year. No incentive to charge more during the periods of low network load.
2. Fixed Time-of-Usage (ToU) price (two, three or more time periods) – a contract with different time periods with different prices, normally peak price and night price at least. Pricing may be different on euros per kWh or on price of contracted power. It is cheaper to charge during non-peak times and it is much more expensive to charge during the day. These time periods and corresponding prices do not vary over a year. Notice that:
    - ToU V2G pricing is not likely to take place (the use of batteries is, and probably will remain, too expensive to offer such a service against attractive price levels, see also 6.4 (V2G perspectives)).
    - A variation of ToU with prices that include the ability to interrupt the supply is also possible.
3. Spot Pricing for consumption and generation – a contract with a totally variable pricing, with variations during the day, week and year. The energy is charged at real-time values and in order for the user to benefit it must be very interactive

For the further smart charging development it is necessary to continue with the IEC 15118 standard. It is a standard for communication between vehicle and EVSE to support (among others) also the smart grid applications: The standard IEC 15118 defines multiple use cases, and covers all OSI-model protocol levels, from application layer down to the physical layer. Its integral element is the access to the EV's battery, which is the precondition for full utilisation of the smart charging potential.

3.6 Various scenarios and the DSO implications

This section describes the possible business scenarios of EV integration in the grid based on the whole value chain perspective and is based on the analysis conducted mainly in the G4V and the Green eMotion FP7 projects, but it also leveraged the Eurelectric position paper [54].

The impact of a single EV on the power system would be negligible. However, a large penetration of EVs is expected, and co-ordination of clustered groups would also be desirable, not only as a business opportunity but also as a new virtual agent that would impact the power system by controlling its demand.

Safety aspects and a stable power supply are of utmost importance for both customers and DSOs, therefore the influence of battery charger characteristics on the electricity network has to be properly addressed. Protection against electric shocks and effects of short circuit has to be carefully assessed to ensure safe use for consumers. When in charging mode connected to the EVSE, the vehicle should at a minimum comply with the standards that apply to electrical equipment used in similar circumstances according R100rev2, [55] new revision 3 under discussion and also according future results of WG1 ISO IEC JPT 17409 [56] activities related to "Electrically propelled road vehicle - Safety requirements for connection to an external electric power supply". Electro-mobility will introduce new constraints on the grid and electric vehicles in particular with regards to Electromagnetic compatibility which should be minimised by employing state-of-the-art technology. EV have to comply also in charging mode connected to EVSE R010 rev4 [57] for EMC.

When aiming at integrating EVs in distribution grids, the DSO may opt for either reinforcing the grid or for managing the load (or a combination of both strategies).Therefore, by varying the weight of grid reinforcements and load management, a number of business scenarios has been selected for the analysis. Their description is based on the general architecture depicted in Figure 53:

- Conventional, where no load management is considered and EV integration must be faced through grid reinforcements and, generally, investing on widening the existing hosting capacity.
- Safe: adding soft fleet-focused load management to the conventional grid reinforcements, possibly reducing the effort in widening the hosting capacity only through copper investments.
- Proactive load management: dealing with massive EV penetration and minimizing the needs for grid reinforcements.
- Smart grid, with a granular control of EVs load management that allows for optimisation of hosting capacity, additionally considering the local connection of DER that can benefit from EV penetration, via a positive feedback loop.

Network operators are the main responsible parties for system efficiency and their business model is based on operation and maintenance of the network with quality requirements fixed by national authorities, in compliance with EU targets. They plan and operate their network assets on a daily basis, both from a service provision and a business management point of view. As a regulated activity, system operation is remunerated for the compliance of some defined objectives, which certainly condition the business strategy of

system operators. Therefore, it would be very important to define energy efficiency activities as eligible for compensation and with clear and appropriate procedures.

The distribution activity remuneration criteria should seek to stimulate the improvement of management efficiency, technical and economic efficiency and power supply quality, as well as the reduction of electrical losses in distribution networks and the rise of DER hosting capacity via a large-scale DR program. Distribution companies should be remunerated for the investments necessary to guarantee an efficient electricity distribution at the lowest cost (in the long term). Even if other aspects such as demand-side management, the use of storage devices, load reduction and, in general, the efficient management of the network are currently encouraged by legislative documents, the economic compensation derived from applying such strategies is not clearly defined. This is an important point for system operators in order to put in place strategies of this kind. In order to encourage DSOs to invest in DR services in the e-mobility business, in addition to technical aspects, economic implications have to be clearly defined, so as to achieve an efficient planning of network development and to design an effective portfolio of operational strategies suitable for an optimum management of the system.

Incentives favouring a more environmentally friendly use of resources might be required to define EVs' charging profile according to the current generation mix and the availability of local DERs. In some cases and depending on the country, periods with higher level of renewable energy might be made cheaper for end users and, in these situations, electricity prices become a "sustainable" reference to plan EV charging periods.

The key aspect for the integration of EVs in the distribution network will be the management of the power since its impact can be mitigated if the charging can be done outside peak hours. It is then important to ensure that the EV charging peak is not coinciding with the peak demand on the system wide and local level.

In summary, the three major impacts in network operation due to a massive arrival of EV are expected:

- Local congestion in lines or cables and/or voltage issues. A good management of the power consumed or produced by the EVs is needed to avoid large investments in the network.
- The operator will need good forecasting tools to determine the power flows in his network and then operate it with limited margins.
- Some problems may occur with harmonic over voltages. Technically, solutions are available but the set of applicable standards should be updated to cover the cases of networks with most of the loads and local producer being connected to the network through power electronic interfaces.

DSO is the main entity responsible for the quality of electricity supply.

3.7 Summary

The European authorities from the electricity domain believe that the charging process that takes place between electric vehicles and charge spots need to be coordinated, thereby taking the electricity grid constraints and electricity generation capacities into account. Normal AC charging mode 3, already available in domestic settings (home and work) as well

required for public charging, should be the dominant charging method – not only due to the possibility of integrating RES into the existing electricity system, but also as a means of stabilising the grid through “smart”, i.e. load controlled, charging processes. This will also minimise the costs for rolling out additional infrastructure and provide a user-friendly solution. Provided that EVs are charged in a smart, load controlled way, we see no reason to doubt that the functioning of market forces will turn EVs into a competitive transport technology. Over time, the market, stakeholders, standards and regulation will signal which charging functionalities and facilities are needed and EV customers’ desire and are willing to pay for.

DSOs are influenced by projected increase of EV sales and will represent new type of the load on various voltage levels. Grid operators are responsible for the quality of electricity supply, which can be maintained with the sufficient amount of information. From this point of view the most suitable scenario is the one, where the charging infrastructure is managed in a “smart” way, is interoperable with other devices from the Smart Metering concept and offers variety of services to efficiently integrate EVs into existing networks.

4 SMART CHARGING

At the current state of development Smart Charging, despite having a common understanding in the scientific world but does not have a single clear definition. There may be several reasons for this non-existence of a definition but the most apparent one would be the fact that the huge amount of possibilities, in functionalities, services, actors, and many more that the term Smart Charging generates, is so enormous that a single and simple definition might even not be sufficient to cover all these possibilities.

The process of EV charging is relevant for EV user and for DSO but its understanding is different for user and operator. There are three issues important from EV user perspective:

- Charging current should be controlled according to the OEM recommended procedures in order to ensure maximum battery lifetime and prevent from damages.
- Battery should be fully charged up to the time set by EV user
- Battery should be charged with minimal cost

If controller fulfil requirements listed above, the procedure can be called Smart Charging (from EV user point of view).

The system operator regards charging as the smart, only if the network is fully monitored, he has information about power system operation and he is able to control of each charger preventing the grid against overloads.

The EV can be used by the operator as a energy storage if charger connected allows for bi-directional power flows. Then, the charger is able to provide both functions, Smart Charging while charging batteries and V2G while discharging. The V2G is essential for peak shaving and Ancillary Services.

Chargers can be mounted on board EV and then the localization of mobile loads (EV) controlled by the operator is a function of time. In case of off board PWM chargers (permanently connected to the grid) it can be additionally equipped with autonomous controller allowing for V2G provision such as reactive power compensation, load balancing (symmetrisation) and harmonics reduction.

According to above comments, it is difficult to strictly distinguish Smart Charging and V2G. They are provided by the same devices and can be proceeded at the same time or sequentially. Due to authors of Smart Charging chapter and V2G chapter will not able to separate of these topics. Therefore some aspects are analysed in both chapters but in different context. Both issues are also summarized together in the Chapter 5.6.

In the first section of this chapter a definition for Smart Charging will be given which remains valid within the COTEVOS project. Afterwards the functionalities of Smart Charging and the requirements from the EV user and Smart Grid view will be shown. Later several Smart Charging techniques are explained and preconditions listed. Finally some Use Cases from other projects are described, followed by a conclusion.

4.1 Definition

In this chapter COTEVOS gives its own interpretation of a definition for Smart Charging as well as a listing of other definitions provided by other EV related platforms.

4.1.1 Smart Charging in COTEVOS

The COTEVOS Definition of Smart Charging is strongly aligned with the CEN/CENELEC definition of Smart Charging (see section 4.1.2.1) and reads as follows:

> *Smart Charging is a service oriented method to charge electric vehicles facilitated by communication between the electric vehicle and all other involved parties, such as e.g. DSO, Energy Provider, etc. Therein services refer to user services, distribution grid services and system wide services. The charging process is thereby controlled in a way such that multiple factors as grid stability, load flow management, energy pricing and many more, are considered to achieve a beneficial result for all contributing parties.*

4.1.2 Definitions of Smart Charging from other resources

4.1.2.1 **CEN/CENELEC: WG Smart Charging**

Smart Charging of an electric vehicle is when the charging cycle can be altered by external events, allowing for adaptive charging habits that result in a more grid friendly behaviour and more efficient management of power demand and energy used during the charging process. Smart Charging is facilitated by information and communication between E-Mobility and smart grid technologies and associated actors.

External events in this context can be classified as implicit changes to the physical properties of the grid as well as the explicit communication of information and services between E-Mobility and smart grid technologies, service providers and operators but also user interaction with the vehicle or the station.

Besides Smart Charging there is also ‘Value Added Service’ like location and reservation of charging spots, easy and secure identification methods and other services that could make the charging easier for the user. However, ‘Value Added Services’ might interact with Smart Charging sequences in several ways.

Key to the requirements outlined for Smart Charging is interoperability between actors, e-mobility and smart grid technologies. Two or more systems (devices or components) are interoperable, if the two or more systems are able to perform cooperatively a specific function by using information which is exchanged.

Interoperability in the context of Smart Charging describes the integration of tasks and refers to the exchange of information between two or more devices from the same actor, or different actors and the use of information for correct cooperation. The functionality of Smart

Charging is to optimize the charging of the vehicle taking into account different goals like user, battery, grid and energy friendliness. Therefore it describes the compatibility of components within a charging system which will ensure access to and use of a safe and reliable charge for an electric vehicle [71].

4.1.2.2 **Smart Charging in the CEN/CENELEC/ETSI M/468 WG**

Smart Charging is the ability for an electric vehicle to integrate into the whole power system in a grid- and user-friendly way. Smart Charging must facilitate the security (reliability) of supply while meeting the mobility constraints and requirements of the user. To achieve those goals in a safe, secure, reliable, sustainable and efficient manner, information needs to be exchanged between different stakeholders.

4.1.2.3 **Smart Charging in the Danish Nikola Project**

"The act of influencing the timing, rate and direction of the power and energy exchanged between the EV battery and the grid to yield benefits for owner, system, and society."

Three general "Smart Charging" behaviours: Adaptive charging, Energy backup, ancillary services (We can say Smart Charging covers all the behaviours to simplify our approach).

4.1.2.4 **Smart Charging in SmartCharging.nl**

Smart Charging is a technology that makes Smart Charging of electric vehicles accessible to all. 'Smart' means that the available grid capacity is handled in a way that always allows consumers to fully charge their battery. And this takes place without the grid becoming overloaded – even if large groups of consumers want to 'fill up' at the same time and in the same place [84].

4.1.2.5 **Smart Charging referred to OCPP 2.0**

Smart Charging in OCPP refers to a controlled charging process where a charge point or a central system or both can set constraints to the amount of power that is delivered during the course of a charge transaction. It can be used at a local level to limit the total amount of power that may be used by a group of charge points, for example in a parking garage. It can also be used on a global level to adjust the power consumption of charge points to match the power generation capability of the grid or the availability of renewable energy sources.

In order to control the amount of power that an EV may draw from a charge point some form of vehicle to EVSE or grid communication is necessary. OCPP 2.0 has been designed to support the ISO/IEC 15118 standard for communication between vehicle (EV) and charge point (EVSE). However, it is anticipated that for the coming years, the majority of EVs will

only support the Mode 3 PWM signal, so care has been taken to support Smart Charging with PWM as well.

4.2 Envisioned Smart Charging functionalities

From the smart charge definition in section 4.1.1 it was derived that Smart Charging functionality comprises three different kinds of services. These are user services, distribution grid services and system wide services.

The services are grouped according to the level of the power system to which they add value and follow the structure of the Danish Nikola project (see Figure 54).

The user services describe the information-based services that will grant the user access to Smart Charging. The distribution grid services describe the services needed to satisfy the needs of distribution level and islanded electricity networks. Finally, the system wide services describe the services needed to satisfy the needs regarding the general transmission level grid, including ancillary services used to support its operation.

Where distribution and system wide services are based on power and energy, the user services are based on information to inform and empower the end user in regards to Smart Charging.

These three service groups can be mapped to the four Smart Charging requirements that are formulated by the Working Group Sustainable Processes (SG-CF/SP) (Mandate M/490). These four requirements are: Customer defined charging, Grid optimized charging, E-production optimization and Renewable mix charging. The definition of these requirements is explained in the following sections. Table 14 reveals the mapping of the Smart Charging services to the M/490 requirements.

Table 14. Smart Charging services according to M/490

M/490 Requirement	Smart Charging service
Customer defined charging	User service
Grid optimized charging	Distribution Grid- and System-wide Service
E-Production Optimization & Renewable Mix Charging	System-wide Service

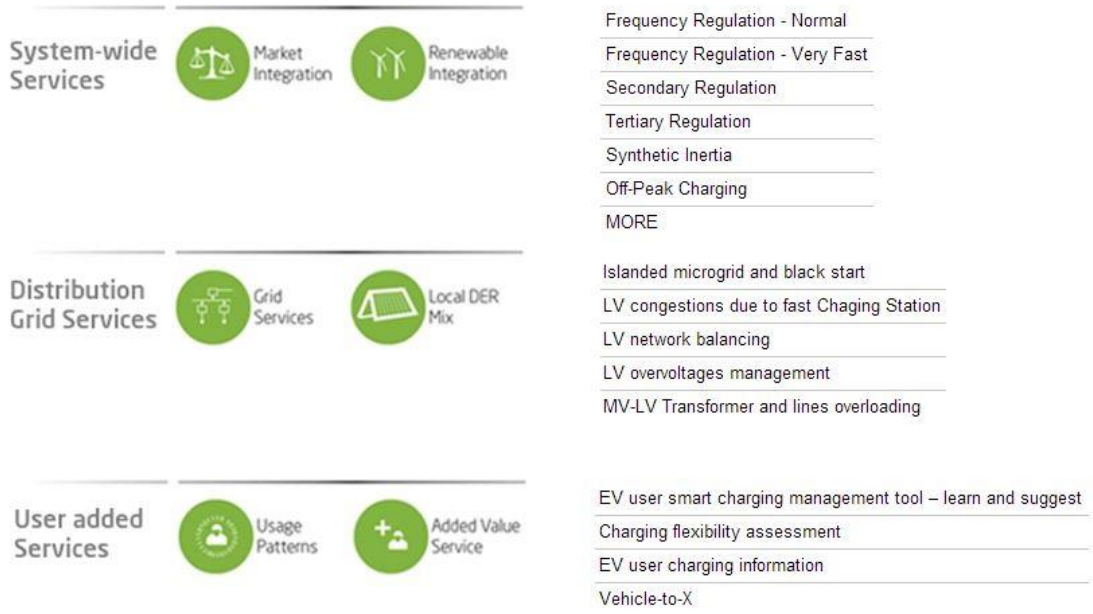


Figure 54. Services mapped to the level of the power system to which they add value [92]

4.2.1 User services

The services investigated in this topic are primarily focused on how to understand, inform and empower the EV user before altering the charging behaviour of the vehicle batteries. These services will bridge the user's requirements with Smart Charging services and can be said to be part of the enabling technology that will facilitate all other services.

Examples of user services are:

- Charge management
  - Configurable time of departure
  - Configurable target state of charge at time of departure
  - Instant charge (smart charge override)
- Charging information

The primary aim of Smart Charging here is to maximize consumer convenience (facilitate EV users, optimize charging conditions and respect customer needs and requirements) through the use of available infrastructure (grid connected charging stations). To facilitate the EV user, Smart Charging should include the customer needs.

4.2.2 Distribution grid services

These services are related with the integration of the electric vehicle (EV) in the distribution grids as part of the operational and strategic target of a distribution system operator. Parameters addressed include voltage, thermal and reactive power limits. This

group also includes islanded and microgrid scenarios where EV services are used to maintain a stable and secure operation.

Examples of distribution grid services are:

- Islanded microgrid and black start
- LV congestions management
- LV network balancing
- LV overvoltage management
- MV-LV Transformer and lines overloading management.

The construction of the EV infrastructure is preferably done within the available grid capacity also to avoid unnecessary grid investments. Since the grid has limited capacity and can have voltage constraints, optimization is used to prevent grid failures or power quality issues, using load control (eventually with use of (fixed) storage systems or vehicle to grid (V2G)).

4.2.3 System-wide services

System wide services are related to how the electric vehicle can aid in maintaining a cost-efficient secure power system with a high degree of renewable production. This includes ancillary services, bulk energy trade and use of system-wide renewables.

Examples of system-wide services are:

- Frequency Regulation - Normal
- Frequency Regulation - Very Fast
- Secondary Regulation
- Tertiary Regulation
- Synthetic Inertia
- Adaptive Charging
- MORE (Mother of all regulation).

Regarding the E-Production optimization this concerns optimization (cost-effectiveness) of electricity production (peak shaving) and avoiding unnecessary investment in production capacity, using load control (eventually with use of (fixed) storage systems or vehicle to grid (V2G)).

In terms of Renewable mix charging these services are related to all forms of Smart Charging (customer defined, grid optimized and E-Production optimization). In the first phase, when EVs are mainly used by “early adopters”, it can be expected that charging from RES is welcomed by this group of EV users.

4.3 Smart Charging requirements from the EV user point of view

Electric vehicles (EVs) are identified as one of the solutions for a more sustainable transport system, and the role of ICT is crucial in the managing of the infrastructure to enable a mass deployment of EVs. The charging of a large numbers of vehicles simultaneously across the electricity grid is challenging. For the optimisation of electro-mobility and energy

use, it is deemed to be indispensable to move towards charging electric vehicles, as well as other loads, in a smart way.

Smart Charging aims to satisfy the needs of an EV user through an optimal charging process that adjusts amongst others power load profile considering systems capacities, grid stability and efficient management of power demand and energy use.

At least the following elements are to be considered in the evaluation:

- Power system constraints like grid congestions due to peak and voltage stability;
- Energy Price, based on supply and demand from energy market;
- Energy Mix with the requested amount of renewable energy as far as possible.

Depending on the business model adopted, the definition of Smart Charging points out different aspects. From EV user perspective, Smart Charging must facilitate the security (reliability) of supply while meeting the mobility constraints and requirements of the user. The exchange of information between the different actors involved in the process of charging in a “smart” way is essential in achieving those goals in a safe, secure, reliable, sustainable and efficient manner.

Considering a “basic” EV user, it could be said that its priorities are:

- Prices and
- Functionality.

The best solution for the EV user perspective is undoubtedly to have the car charged with the amount of energy, required by EV user as soon as possible and for the cheapest price. Each other possible choice of the user is the result of a trade-off between the two aspects, as in most commercial situations: lower functionalities can be accepted for a cheaper price, while it is expected to pay more for a better service. In the case of “Smart Charging”, the price corresponds to the charging service bill, while the functionality can be expressed as the charging speed and effectiveness. The user can therefore easily accept a Smart Charging procedure if this corresponds to an economically convenient choice. The advantage could come both from a “price following” charging scheme or, as alternative, from a discount offered by the DSO/Retailer as compensation for improving the grid stability.

Considering a more “advanced” user, another aspect could come out:

- Environmental impact and CO_2 emissions;

This could have a non-negligible importance for users particularly devoted to environmental issues, which can be often found among the EV “early adopters”. In this case, the user can ask for a particular charging schedule properly designed to rely on renewable and clean energy.

For both kinds of users, anyway, some necessary constraints and requirements coming from the EV user exist:

- Energy required and time of departure defined by EV user
- Reduction of the charging cost e.g. taking into account price signals, if available, and choosing to charge during off-peak hours
- Minimum level of battery charging for permitting the usage of EV under emergency conditions.

The same aspects just pointed out for Smart Charging can be applied (and probably amplified) in a reverse energy flow (V2G) perspective. In particular, the acceptance of usage of EVs as a supporting load for grid needs can happen only under remunerating condition (pricing incentives for EV user).

Given that, it is worth mentioning that, in addition to Smart Charging itself, ICT services for charging can be exploited also for the so-called Value Added Services (VAS), as location and reservation of charging spots, easy and secure identification methods and other services that could make charging easier for the user.

For EV user is very important to drive in urban areas with high traffic density and park with the possibility to charge. The information about location and the availability of the charging station represents an added value. The definition of Value Added Services for EV user includes all kinds of services related to charging and Smart Charging, like:

- Route based or location-based information services
- Parking Reservations
- Energy efficiency optimization and
- Mechanism for CO_2 reduction

4.4 Smart Charging requirements from the smart grid point of view

Electricity grid and its management need to respond to the growing use of renewable energy (mostly wind and solar) and the increasing share of distributed generation units. This evolution has made the energy flows less predictable with the rise of energy flow from LV to HV networks. The energy production from distributed generation (for example solar and wind farms) is unpredictable and not related to the needs of the whole power system. Furthermore, it is often highly dependent on external circumstances, such as current weather conditions. This presents a problem for the power system, which must ensure a balance between production and consumption of energy at all times. The power system requires more operating reserve (meaning more costly investments) to accommodate the unreliable and fluctuating output from distributed generation. The conditions outlined above have a great effect on the ensuring of balance between produced and consumed energy on the national level and on the operation and planning of grid development regarding power flows (strain on different elements of the network) and local voltage conditions.

The economic climate rarely allows an increase in the rate of investments in the power system and an increase of system's operational costs. The solution for sustainable operation of the power system therefore lies in active management of the distributed generation and energy consumption on the consumption side in order to make the system more cost effective. Such management requires a new approach to the management of the power system, a strong support in the information system, and appropriate physical equipment at the location of energy consumers (i.e. end users and distributed generation). Due to the requirements for advanced information systems and coordinated actions of both the energy infrastructure and its users, the described approach is referred to as Smart Grid.

In this context, a large-scale Smart Charging system for electric vehicles can clearly be an advantage for the functioning of the power system. When EVs are connected to Smart Charging stations with the option of remote control, their charging can be stopped (or the

charging current lowered) when the power system faces higher loads and resumed at a later time. This decreases the power consumption within the network, with the same effect on the balance between energy production and consumption as if the operating reserve in a designated power plant had been activated. Additionally, EVs as flexible consumers can participate in the process of distribution network management, being used as part of management of local conditions in the grid.

The management of EV charging load should consider the needs of EV users and only reduce the charging load when there is enough time available to fully charge the vehicle later on. This could mostly be done with EVs which are charging at home or during working hours, where the available charging time is considerably longer that the time needed to recharge the battery.

An advanced EV charging management option in the power system is to use its battery as an energy storage device. In this case, the EV does not function merely as an equivalent to reserve power (in the sense of lowering consumption when needed), but can also store excess energy in its battery and return it to the network in times of shortages. In combination with smart grid functionalities, EVs can strongly benefit the increase of energy production from renewable sources (like wind farms); a larger number of EVs connected to the network can store the otherwise curtailed energy produced by wind farms when their output exceeds the demand of the power system. This energy can be later returned to the network or used for driving needs. Besides enabling a higher share of energy produced by wind farms to be used in the grid, this scenario also supports combinations with photovoltaics and micro-cogeneration. EVs thus indirectly facilitate the use of a higher share of renewable energy in the energy portfolio of energy producers and traders.

Considering the daily energy needs of a certain load area, energy consumption of a single EV seems insignificant. However, if we assume only a 1% share of EVs, their combined charging capacity presents a significant amount of power which could be used for energy adjustments in the power system. With the use of proper control systems and adequately equipped vehicles and EVSE, this power can be used to control the consumption according to local conditions (energy flow and overloads in the power distribution network) and national needs (balance between the total output of power plants and total consumption).

4.4.1 Smart Grid Stakeholders (Grid Related)

A number of smart grid stakeholders have a direct relation with the grid and thereby have requirements with respect to Smart Charging. In this section we introduce the three grid related stakeholders namely: DSO, Energy Provider and EVSE Operator. After the introduction we explain the role of the stakeholder and describe their Smart Charging requirements. Definitions are aligned with CEN-CENELEC WG Smart Charging [71].

4.4.1.1 **DSO**

According to European Directives a Distributed System Operator (DSO) is "a natural or legal person responsible for operating, ensuring the maintenance of and if necessary,

developing the distribution system in a given area and, where applicable, its interconnections with other systems and for ensuring the long-term ability of the system to meet reasonable demands for the distribution of electricity". Moreover, the DSO is responsible for regional grid access and grid stability, integration of renewable at the distribution level and regional load balancing.

Safety of supply (e.g. no congestions) is important for a DSO. Therefore the DSO is trying to secure access to energy and 'safety of supply' either by a smart grid or by a combination of a smart grid and manageable load, like shifting the EV charge to 'off-peak' hours. This is also addressed in the ISO-IEC 15118-1 concerning the responsibility for the voltage stability in the distribution grid (medium and low voltage power grid).

Role of actor

- Electricity distribution is the final stage in the physical delivery of electricity to the delivery point (e.g. end user, EVSE or parking operator).
- A distribution system's network carries electricity from the transmission grid and delivers it to consumers. Typically, the network would include medium-voltage power lines, electrical substations and low-voltage distribution networks with associated equipment. Depending on national distribution regulations, the DSO may also be responsible for metering the energy (Metering Operator).

Needs

For the energy sector the integration of EVs into the smart grid, taking the distribution system operator (DSO) for an example, is interested in congestion management, spinning reserves and frequency regulation on the distribution network level in order to adequately respond to an energy supply shortage or oversupply situation. Those needs can be satisfied by controllable, decentralized loads and intelligent devices. DSOs typically respond with innovation when driven by economic impacts or regulatory mandates. Utilities are likely to find bi-directional power flow of BEVs in a V2G system attractive for two main reasons:

1. as a storage medium and load-levelling sink for intermittent renewable energy and
2. as a mean of fulfilling their grid support/ancillary services obligations.

Especially EVs represent such intelligent devices and have an enormous load-shifting potential. Another important application of EVs is their usage for power factor correction in order to compensate for phase shifts. Going down a level to the domestic energy supply, controlling the charging and discharging processes at a smart home may help to avoid peaks and maximize the yield of energy supplied by renewables such as PV panels.

Managed charging of EVs could provide significant value to both the energy system and consumers: shifting of charging demand and provision of various Vehicle-To-Building (V2B) or Vehicle-To-Grid (V2G) services. Coupled with potential enhancement of battery lifetime it is likely to have a strong business case if the various technical barriers can be overcome.

Hence much more work needs to be done – in conjunction with vehicle manufacturers (OEMs) and battery manufacturers – to ascertain exactly what the quantifiable benefits might be, and the best charging methodologies to employ, in order to maximize the value of any managed-charging proposition. Detailed work is required to fully understand the communications protocols, pathways and interfaces needed to implement managed charging

and V2B/V2G. ISO 15118 is a developing Standard specifying the communication between EVs and the Electric Vehicle Supply Equipment (EVSE – the “charger”).

One of the key barriers to effective implementation of V2B/V2G is the difficulty of communication between the ‘energy manager’ and the EV (and, more specifically, the battery), to fully understand the available capabilities of the battery at the required time, and to evaluate the costs and benefits of managed charging due to battery ageing. With current EVs, the OEMs closely guard all information flows to/from the vehicle, severely limiting the possibilities for managed charging. It might be possible to implement V2B/V2G via an OEM’s back-end server connected into the energy-manager’s systems, but there would be significant advantages in terms of system cost, robustness, flexibility and speed-of-response to using a local smart-home connection to the EV BMS, and the report investigates this opportunity.

The ISO 15118 standard allows the EV as well as the EVSE/Smart Home Control system to influence the charging profile of the battery. Until now, this was not possible due to a lack of communication ability. This ability enables charging the battery under consideration of different factors, even without the possibility of bidirectional power flow: From the user perspective, these are the electricity cost and impact of the charging profile on battery aging. From the grid/utility operator view, the load situation on the electricity grid is important. Under the assumption that the user has programmed an estimated departure time, the utility operator has the possibility to influence the charging behaviour of the vehicle by altering the price. In the case of the utility provider being the DSO this price alteration could be a reduced network usage fee. In case of the utility provider being the energy provider this price can directly be the energy price. However, this is afflicted with some degree of uncertainty: As the demands of the battery, defined by the BMS of the vehicle, take precedence for charging schedule negotiation, the outcome may differ from the favoured charging profile of the grid operator [85],[86].

List of needs for DSO

- Congestion management
- Power Quality Maintenance
- Ancillary services (e.g.: voltage control, reactive power control, phase balancing)
- Blackout recovery
- Grid investment costs reduction
- Communication Interface to EVSE Operator

4.4.1.2 **Energy Provider**

The Energy provider is an entity on the market selling electrical energy to consumers, in compliance with the regulation for market organization. It can also have a grid access contract with the TSO or DSO.

Role of actor

In addition, multiple combinations of different grid user groups (e.g. those grid users that do both consume and produce electricity) exist. An Electricity Supply Reytailer (ESR) is in relation with a Balance Responsible Party according to the electricity market organization.

Needs

Energy provider is a role which functionalities are expanding in line with the energy market development. The provider does not focus on the electricity supply only, but integrates with other services and utilizes the broad network of customers. Currently competitors of energy utilities (energy providers) are becoming the telco companies, which have similar business model approaching broad network of customers with services. This concerns the EV services as well.

Participation in Smart Charging services is primarily a function of minimum required storage capacity, vehicle SOC (state of charge), scheduled lead time for next operation of vehicle, electricity rates and market signals (e.g. price, renewable mix, regulation). A single vehicle battery has little impact on grid operations, but when a large number of vehicles are available, the aggregated battery storage capacity increases to the point that it may have a significant impact. The role of the aggregator service provider or energy provider would be to manage groups of battery sources to provide the overall service to the electrical utility or DSO. The aggregator provides a single point of contact to manage the entire load/source and to guarantee and certify the participation level. The aggregator enrolls and integrates participants, assures sufficient availability, passes through control signals, validates participation and reconciles payment streams for the market services.

Services for buildings and management of buildings are areas where energy providers are increasing their presence. In this case vehicle-to-building (V2B) is relevant concept where batteries of electric vehicles can be utilized. For utility the benefit of bi-directional charging would be different for V2G and V2B functionality. In a V2B scenario, the utility may not be directly involved in the bi-directional electricity flow and the building owner uses the bi-directional capability to reduce the building demand during on-peak times. The reduction in the building sector owner's peak demand and total electrical kilowatt hour usage can be an attractive motivator to induce the owner's participation. The attractiveness of V2B is less than V2G for a utility because only peak demand is reduced and no electricity storage is made available to the utility. On the other hand new services connected with V2B functionality are interesting for energy providers even in case when the storage function is not the priority.

List of needs for Energy Provider

- Load Management
- Communication Interface to EMSP
- Communication Interface to EVSE Operator (possibly via EMSP)
- Clarification of whom the energy is being sold to (EV user / EVSE Operator)

4.4.1.3 **EVSE Operator**

The EVSEO is the actor which manages and maintains the charging spots. EVSEO operates at least one EVSE as a service for E-Mobility Service Providers (EMSPs) and their customers (EV users) but has no continuous contractual relation to EV users.

Its responsibilities may include control and maintenance of EVSEs, purchase of energy for charging on its EVSE, management of identification, authorization and payment for charging and dealing with higher entities (energy supplier/aggregator, EMSP, DSO) for the procurement of electricity and provision of other services related to charging on its EVSE

such as receiving and executing charging plans, negotiating charging capabilities, executing charging service request within boundaries (grid capacity, RE/E-availability), energy metering.

Although the roles of EVSEO and of EMSP are often carried out by the same entity, the role of EVSEO shall be treated as separate from the role of EMSP, which has contracts with EV users for all services related to the EV charging, but doesn't necessarily also operate the EVSE at which the customer wants to charge.

The controlled interaction between the EV and the grid is referred to as Smart Charging (see 4.1.1). An efficient functioning of this process (integrating the EV charging process into control systems of the power system), a power connection (conductive or inductive) with the EV and a reliable communication connection for integration of Smart Charging into a smart grid system are needed.

Outside V2G functionalities, EVs can be integrated into smart grid systems in the following ways:

- reduction of EV charging load can provide an equivalent to short-term power reserve for the grid during problems with production units. Execution of load reduction, as well as its control and monitoring, is relatively simple, following the TSO/DSO request to lower consumption;
- demand response to tackle local overload of elements in the network and improve voltage conditions: executed on the DSO's request with predefined charging load schedule to be applied to the EVSE (charging sessions) in a certain load area;
- integration of EV charging into demand response schemes for the needs of Imbalance Settlement Responsible: EVs as flexible loads can participate in the management of total demand of a group of network users (consumers and producers), which are members of the same balance group.

EVSEO's Smart Charging role

EVSEO is the main actor for Smart Charging execution whose role comprises load management activities according to DSO's requests, dynamic tariffing and integration of EV charging into balance groups. EVSEO can also strive to optimise total load profile of the consumers and producers that are connected to a grid user's internal network.

To perform these tasks, EVSEO requires specialized control centres/systems which offer a management tool for control and maintenance of charging infrastructure and related administrative tasks.

EVSEO's direct involvement in Smart Charging can include:

- acquisition of technical data from the EV (connectivity properties, technical parameters of min./max. charging load),
- acquisition of data from EV users about their preferences (required energy, available charging time window, confirmation to include their EV charging into load management schemes),
- acquisition of relevant technical parameters from the grid,
- processing of requests received from DSO about total EV charging load in a certain load area,

- processing of requests received from market actors about total EV charging load of EVSE included in a certain balance group,
- determination of initial charging schedule (load profile) for each charging session, taking into account the aforementioned parameters,
- rescheduling of charging load profiles according to real-time requirements of DSO or market actors,
- acquisition of data from EVSE about current status of each charging session.

EVSEO's indirect involvement in Smart Charging includes:

- execution of preliminary negotiations with DSO and market actors about technical and financial parameters of EVSEO services on offer,
- acquisition of final charging session data (actual load pattern) from EVSE and forward it to other actors if necessary.

To perform Smart Charging the EVSEO can require the following data:

- Data from charging infrastructure,
- Data from the grid,
- Data from the energy market,
- Data from EV and EV user

To perform Smart Charging the EVSEO requires the following data:

Data from charging infrastructure

Acquisition of data from charging infrastructure is an internal technical issue of the EVSEO. The information derived from EVSE contains data related to:

- EVSE and grid connection data: maximum load of individual charging spot and EVSE, maximum load at the grid connection point for a group of EVSE, and the wiring scheme of individual charging spots (which of the phases in a three-phase system is wired to the pin in the socket-outlet which supplies the EV battery in case of single-phase charging),
- status of EVSE: out of operation (i.e. under maintenance, failure), free, occupied,
- charging process: time of start of charging, energy delivered from the beginning of charging or during predefined time intervals (e.g. 15 minutes).

EVSE and grid connection data are static and known to the EVSEO.

Data on the current status of EVSE and the charging process are available to the EVSE from Smart Charging stations with an active communication link to the EVSEO control centre.

Data from the grid

This data represents external grid related conditions which influence the scheduling of charging:

- Affiliation of individual EVSE to a load area(s): this information is provided by the DSO and is used if DSO requires EVSEO to follow a load schedule for an EVSE in a certain load area. In general, these load areas are hierarchically organized; therefore any individual EVSE may belong to several (wider or smaller) load areas;
- Requirements from the DSO related to load schedule in a certain load area,

- Operation and operation schedules of other consumers/producers connected to the internal grid of the network user (via the same grid connection point from which the EVSE is supplied): in this case, the static parameters (maximum load at grid connection point) are not sufficient for the EVSEO to determine the target load schedule of EV charging. The real target load is represented by the maximum load (or load schedule) at grid connection point with deducted actual load (or load schedule) of other consumers/producers connected to the same internal grid.

Data from the energy market

This data represents external market related conditions which influence the scheduling of charging:

- Appurtenance of individual EVSE to balance group: this information is provided by the balance responsible party,
- Requirement from the balance responsible party related to load schedule of EVSE belonging to the same balance group.

Data from EV and EV user.

This data represents user's (EV's) input:

- Type of EV charger: based on current in individual phases of a charging spot, the EVSE can determine whether the EV is equipped with 3-phase or single-phase charger,
- Maximum (or minimum) charging power of EV: represents the lowest value among the following: maximum power of charging spot, cable assembly and EV charger. The maximum power of charging spot is known to the EVSEO. The maximum power of cable assembly is acquired by the EVSE from the EV according to the standard IEC 61851. As for the maximum power of EV charger, this information can't be acquired automatically in the current state of technology (and standardisation);
- Required energy: represents the amount of energy (kWh) that the EV user wants to receive during the charging session (within the time available for charging). In current state of technology (and standardisation), this information can't be acquired automatically;
- Time available for charging: duration of charging, as specified by the EV user. The time of beginning of charging and the time available for charging determines the anticipated time of end of charging, when the EV user expects that the EV battery has been supplied with the required energy. In current state of technology (and standardisation), this information can't be acquired automatically.

The maximum power of EV chargers, the required energy and time available for charging form the so-called "user preferences". The IEC 15118 standard anticipates the introduction of this information into the protocol for data exchange between EV and EVSE; the said standard has been adopted only recently and consequently there are no mass-produced EVs on the market which would support the standard. However, the user preferences can be acquired also directly from the EV user (by use of smartphone or other HMI), or indirectly:

  - Maximum power of EV charger: at the beginning of charging, the EVSE control sets the EV charging power (current) to the lowest value among maximum charging spot power and cable assembly power, It then transmits

the corresponding signal to the EV (IEC 61851). If the actual charging load drawn is lower than the set power, the charging load drawn is considered as the maximum power of EV charger (and thus also maximum charging power). If the actual charging load equals the set power, the maximum EV charger power is apparently higher but at the same time not relevant for the determination of maximum charging power in this case;

- Required energy and time available for charging: these two values may be estimated based on historical data by means of statistical methods applied on data about past charging sessions carried out on individual charging spots or by individual EV user. This method for determination of EV user preferences requires sophisticated mathematical algorithms, but nevertheless provides unreliable results.

Performing Smart Charging by the EVSEO

After all the input data is received, the EVSEO must employ its algorithms to create the charging schedules (time related set points of charging load for each individual charging session) which are then communicated to the EVSE (or a group/cluster of EVSE) and further to the plugged-in EV(s).

This charging schedule (separated by load areas for the DSO and by balance groups for energy market actors) can be determined in real-time based on actual input data or in advance (e.g. day-ahead) based on historical data on past charging sessions. The charging schedule is communicated to the relevant actors to inform them about actual and future charging load (basic schedule) and about flexibility margins (anticipated flexibility of load variations from the basic schedule).

In any regime of operation, the EVSEO must react to modification of grid constraints according to the information received from the DSO and in line with DSO's instructions on required actions that need to be performed to keep the grid operation parameters within the predefined limits. In addition, the EVSEO is also interested to operate the EVSE (end EV loads) in accordance with the needs of energy market actors, since such operation brings him additional economic benefits. Whatever the reason for scheduling (i.e. determination of charging loads which are different from the maximum charging power of each charging) or re-scheduling the charging is, the EVSEO should consider to a maximum possible extent the EV users' preferences.

Scheduling of charging is a complex mathematical problem which must consider:

- grid constraints and appurtenance of charging spots to certain load areas (subject to DSO's requirements),
- EV user preferences related to each individual charging session,
- market conditions and appurtenance of charging spots to certain balance group (subject to energy market actors' requirements).

In solving the optimization problem, the DSO's requirements take precedence (unless they are not mandatory and are subject of contract between the DSO and EVSEO for providing non-binding services) over the requirements of EV users and market actors.

List of EVSEO needs

- Be compliant with Smart Charging technologies

- Metering and grid parameters measuring
- Communication Interface to DSO
- Communication Interface to EV
- Communication Interface to EMSP
- Communication Interface to Energy Provider

4.4.2 Physical Challenges of the Grid

From previous subchapters we can derive that the stakeholders are facing a number of physical challenges in the grid which can be solved or reduced with Smart Charging technology. In this section we have grouped the challenges in three main categories. Firstly, load of the grid where we describe the details regarding to load and congestion of the grid. Secondly, power quality which covers voltage stability and phase balancing. And finally we discuss the imbalance problem of the energy system. Information in this section is aligned with the Grid4Vehicle FP7 project [87],[91] and the Danish project Nikola.

4.4.2.1 **Load of the grid**

Until today, and as long as grid cannot offer full potential of distribution generation management, storage devices management and demand side management, the peak power is, and will be, the dimensioning factor in a power grid. This means that an increase of the peak power will require from the TSO and DSO investments in a stronger grid, being relevant that the EV is an LV load and therefore it is expected that downstream local grid will suffer more stress than upstream grid, especially in low consumption LV areas. Being expected that these new loads will increase the need of new infrastructures and existing assets re-rating, it should also be considered the increase of situations where normal ratings are exceeded, that will effectively shorten the operation assets lifespan, and by this also increase the grid investment.

An example of possible operation reduction lifespan is the MV/LV transformer. Being this asset one of the main LV grid assets it is important to notice that during transformer operation the windings heats up degrading slightly the tape insulation and core material and that, if under normal operation the lifetime of the transformer insulation can be longer than 20 years, when overloading a transformer it will decrease this expected lifetime .

From what is written above, as EV charging will alter typical customer load profiles requiring a stronger grid and a grid more or at least so reliable as today's grid, not only investment increase needs in new infrastructures and existing assets re-rating should be evaluated, but also additional evaluations addressing "loss of life" as a function of EV type and connection time should be performed.

4.4.2.2 **Power Quality**

In Europe the electrical grid has left the stage where the focus was mainly to guarantee a non-interruptible grid, and is in a stage where is required to the operator to run the system in narrow intervals of system parameters values. Due to the increase of home electronic

devices today's consumers are more than in the past exposed and concerned about power quality issues, like voltage variations. Voltage drop is an aspect to consider for reliable operation of distribution networks since it can cause malfunction and damage of electrical equipment, and is particularly relevant in rural network where due to the long line lengths the largest voltage drops usually arise.

Starting by considering a three-phase balanced system, where generated voltages are sinusoidal and equal in magnitude, with the individual phases 120° apart, the increase of EV penetration will result in an increase of voltage drop in all network types (urban, suburban and rural) exhibiting the rural network exhibits the largest voltage drops as expected.

However maintaining an exact voltage balance on all three phases at the point of use is virtually impossible given that single-phase loads are continually connected to, and disconnected from, the power system, and that single-phase loads are not evenly distributed between the three phases, leading to the observation that power systems may be inherently asymmetrical. Furthermore today's loads characteristics, e.g., the proliferation of single-phase nonlinear switch-mode power supply based loads such as computers, can lead to unbalanced levels of distortion between phases which can also make the balancing process more challenging .

Since a major cause of voltage unbalance is the uneven distribution of single-phase loads, which can be continuously changing across a three-phase power system, a problem that can arise with EV is symmetry as the chargers use single phase circuits.

This way, apart from voltage drop, unbalance voltages should also be considered as a consequence of EVs influx, being their importance not only related with adverse impacts to three phase equipment on a power system such as induction motors, power electronic converters and adjustable speed drives but also because under unbalanced conditions the distribution system will incur more losses and heating effects.

From what is written above, as EV charging will alter typical customer load profiles that will directly impact in voltage performance by which the system operator is responsible to maintain in a narrow interval, an analysis of each phase on the network separately seems indispensable in order to capture the full effects of electric vehicle charging on the network.

4.4.2.3 **Imbalance**

Imbalances between electrical generation and load cause deviations in the grid from the optimal 50 Hz frequency. The frequency must then be corrected by minute real time changes in generation output. Increasing amounts of renewable resources in the grid may result in more frequent short term over and under capacity. Increasing amounts of wind power on the grid may result in more unplanned instances of over and under capacity, increasing the average need for primary control services. Slower traditional resources may result in inefficiencies in the system, which go unaddressed because no faster-reacting resource is currently available. By providing very fast, accurate response to frequency changes, we may be able to minimize or in fact decrease the amount of new primary control reserve and components required.

4.5 Smart Charging techniques

Smart Charging techniques use energy flexibility of devices to provide user added services, distribution grid services and system wide services (see 4.2.2). A definition of flexibility is given by the Flexines project [90], [91].

*A device has **flexibility** if it is capable of shifting its production or consumption of energy in time within the boundaries of end-user comfort requirements and without changing its total energy production or consumption.*

In this section we firstly describe the basis technologies behind Smart Charging. Secondly some implementation examples are enumerated.

4.5.1 Power Balance (Frequency stability)

Demand Side Management (DSM) or Load Management has been used in the (mainly still vertically integrated as opposed to unbundled) power industry over the last thirty years with the aim "to reduce energy consumption and improve overall electricity usage efficiency through the implementation of policies and methods that control electricity demand. Demand Side Management (DSM) is usually a task for power companies / utilities to reduce or remove peak load, hence defer the installations of new capacities and distribution facilities. The commonly used methods by utilities for demand side management are: combination of high efficiency generation units, peak-load shaving, load shifting, and operating practices facilitating efficient usage of electricity, etc.". Demand Side Management (DSM) is therefore characterized by a „top-down" approach: the utility decides to implement measures on the demand side to increase system's efficiency.

Demand Response (DR), on the contrary, implies a „bottom-up" approach: the customer becomes active in managing his/her consumption – in order to achieve efficiency gains and by this means monetary/economic benefits. Demand Response (DR) can be defined as "the changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. Further, DR can be also defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized. DR includes all intentional modifications to consumption patterns of electricity of end use customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption". DR aims to reduce electricity consumption in times of high energy cost or network constraints by allowing customers to respond to price or quantity signals.

Demand Side Management and Demand Response can help in providing a solution to the imbalance problem and to power quality maintenance.

4.5.2 Peak Reduction

Peak Shaving: Peak shaving is the ability to control energy consumption during intervals of high demand, in order to limit or reduce demand peaks in the power system. This

technique enables the shift of energy demand in peak periods to periods of lower demand in order to reduce peak loads of power plants or to avoid peak loads on the power grid while maintaining the users comfort level.

Load shedding: Load shedding is the ability to shift of particular loads during periods of high energy demand. An example of load shedding is the remote power down options on air-conditioning units which is used on days with extreme hot temperatures. The usage of this function directly leads to lower peak demands. EVs can support similar options.

Congestion Management: The feature "Congestion Management" is expected to be deployed in case of a critical congestion event in a specific LV load area and is set in a similar way to Load Management, with the exception of being carried out in real-time and do not generate a bid in the long-term smart-grid market. Assuming that the DSO has a smart network in place where most of the MV-LV stations are remotely monitored and controlled (at least the critical ones subject to frequent congestion events), the DSO is able to detect congestions in real time. This smart network considers the full integration of DMS, SCADA, AMS, OMS, to facilitate a high penetration of EV. DSO and EVSE Operator have a contractual relationship, which allows the DSO to send congestion signals to a particular EVSE operator in order to either interrupt charging or reduce the throughput of the EVSE. Whenever the DSO detects grid congestion issues, it intervenes sending a signal to EVSE operators to ensure supply and prevent serious overloads or even blackouts. This feature should be applied only in case of emergency and should be in principle avoided, with the DSO predefining limits for electric mobility consumption that should not be violated by EVSE Operators. The intervention of the DSO is made directly by sending a signal to the EVSE without passing via the market place or a different actor as done by the TSO when activating some ancillary services.

Peak reduction technologies can contribute in solving the congestion problem, phase balancing and voltage problems.

4.5.3 Implementations of Smart Charging

In Europe there are several implementation of Smart Charging. The CEN-CENELEC Work Group Smart Charging described a number of implementations in the E-Mobility Smart Charging report [71]. The following implementations are described in that document::

- Context Aware Charging
- CROME : CROss-border Mobility for Evs
- EDISON VPP
- ELVIIS – Electrical Vehicle Intelligent Infrastructure
- Energy Conservation
- ESBN Winter Trials
- Finseny Project
- GÖRLITZ E-Mobility Smart Charging Solution
- Green eMotion congestion management in DSO business model case
- IntelliCharge by ERDF
- MUGIELEC
- PowerMatcher

- VISMA

4.6 Preconditions for Smart Charging

Before Smart Charging can be executed a number of technical preconditions should be met. This section provides insight in the individual preconditions.

Communication interface specifications

To enable Smart Charging beyond multiple parties, standardized communication interfaces are required:

- Between EV and EVSE
- Between EVSE and EVSE Operator and EMSP
- Between DSO and EVSE Operator or EMSP
- Between EVSE Operator or EMSP and Energy Provider

Communication availability and robustness

Ideally a communication link is always active; however in real operations there exists always a possibility of communication failure. The failure of a communication link should not lead to unsafe situations or cause physical defects (e.g. battery-, feeder- or transformer-defects). Therefore the different entities in a smart charge system should be robust in terms of communication failures.

Grid Monitoring

In order to provide status information of the grid, power quality measurements are needed. Smart Meters and SCADA systems can be used for this monitoring task. The Green eMotion deliverable D4.2 provides a table with the overview of possible measurements which can support the monitoring of the grid:

Table 15. Possible measurements for grid monitoring

Location and/or asset		Device	Measurement
MV/LV substation – Transformer		Current sensor	I
		Voltage sensor	V
		Meter	P&Q ,V
MV/LV substation – LV feeder		Current sensor	I
		Meter	P&Q
Strategic node of the LV network		Voltage sensor	V
Point of delivery	Consumption	Meter	Active energy - P - V - Voltage alarm
	Generation	Meter	Active energy - P - V - Voltage alarm
Internal electric wiring	Consumption / Generation	Battery charger or dedicated sub-meter	Active energy - P

Location awareness in grid topology

Smart Charging techniques rely significantly on physical location in the grid topology (in case of grid optimized Smart Charging). For instance congestion management can only function correctly if there is a common knowledge between the EVSEO and the grid operator about the location of the charging infrastructure. More specifically, there must be knowledge

about where the EVSE is connected to the feeder cable and to which transformer station the feeder cable is connected. Furthermore this location information should be expressed in a standard way that all the related parties can interpret this information. A standard for location and addressing seems welcome if not even inevitable.

Metering and Billing

Depending on the method of financial clearing a Smart Charging service can introduce additional complexity in the metering and billing of energy consumed by the EV. For instance if a smart charge service uses a dynamic tariff for billing, the metering system must have a notion of both energy consumption and the time of energy consumption since the total price of charging session can be build up from different tariffs. Evidently this is more complex than only measuring a cumulative value of kWh and requires smart metering.

Smart Charging preconditions related to EVSEO

EVSE:

- Remote control of EVSE:
  - Mandatory at least on the level of switching on/off the power supply of charging spots;
  - Real SC (with targeted goal – e.g. load of EV charging in a load area in kW or decrease of EV charging load for a certain percentage of power) with consideration of EV users' preferences is optimal only with remote control of charging power;
  - Frequency of load set points communication to EVSE: higher frequency brings more accurate results. On the other hand, the EV battery life cycle is shortened by frequent switching on/off or changing the charging power set points. In the case of energy market related SC (e.g. power control for energy balancing) or of normal daily peak load (which threatens to overload grid components), the sufficient frequency of control signals is every 5-15 minutes. In the case of grid components' overload or low voltage conditions due to peak loads or non-availability of grid elements (outages of power lines and transformers), the control signal to the EVSE must be transmitted immediately after receiving the request or after detection of critical network conditions.
- data about EVSE operation:
  - in a very basic mode of SC (maximum reaction of EVSE to critical condition in the power grid), the data on EVSE operation is not needed for the EVSEO (reaction to DSO's request is in the form of simple switching off all EVSE in a certain load area);
  - For advanced SC, acquisition of data about EVSE operation is mandatory: the EVSEO must know the current status of EVSE (charging status, current charging load, energy delivered during individual charging session, …) to plan the SC control actions and to monitor their execution (in order to determine additional actions in the case of underperformance);
  - Frequency: 5-15 minutes;
- Standards: communication EVSE – EVSEO CC can be an internal EVSEO's issue, but for independence of EVSE manufacturers and EVSE operators a standard is preferred. No dedicated international standards are approved for this communication.

Open communication platforms are commonly used for this communication. OCPP protocol is widely used, while some EVSEOs use their own proprietary solutions.

EV and EV users:

- charging preferences:
  - for determination of charging schedules, the most important are data about the energy to be delivered to EV (required by EV user), the time available for charging, and the maximum power of EV battery charger. However, this data is not absolutely mandatory – it can be estimated by the EVSEO based on statistical analysis of data about past charging sessions;
  - Frequency: acquisition once before the start of charging session;
  - Standards: acquisition by ISO 15118 standard or indirectly from EV user's smartphone or EV's on-board information system.
- EV user's consent for EV load control:
  - Not mandatory but desired in order to consider as much as possible the EV user's needs;
  - Frequency: once before the start of charging session;
  - Standards: by ISO 15118 standard (negotiation about load schedules) or indirectly from EV user's smartphone or EV's on-board information system.
- EV battery charger load control:
  - Real SC (with targeted goal – e.g. load of EV charging in load area in kW or decrease of EV charging load for a certain percentage of power) with consideration of EV users' preferences is optimal only with remote control of charging power;
  - Frequency of load set points communication to EV: see EVSE – Remote control of EVSE. The control signal is transmitted from EVSE to EV immediately after it is received from EVSEO CC. In the case of load schedules (containing time related charging load set points) the frequency of communication depends on duration of each control time window;
  - Standards: IEC 61851 or ISO 15118.

EVSEO:

- back-end support: EVSEO must implement algorithms for Smart Charging (load scheduling) and operate the EVSE infrastructure that supports this implementation on the HW level
- communication with DSO and market actors: EVSEO should have open communication channels toward all other actors for information flow: charging infrastructure current operation data, request for SC actions (EV load variation), metering data, billing data, etc.
- business side: the preconditions for SC are the contractual relations between EVSEO and other actors to determine the SC action's technical parameters (amount, duration, time of activation, …), payment methods and billing details, incentives for EV users to participate in Smart Charging schemes, etc.

4.7 Smart Charging Use Cases

In order to align further work in COTEVOS on the topic of Smart Charging with the work that is already been done in other European EV initiatives we suggest to elaborate further on the existing Smart Charging use cases. The CEN-CENELEC-ETSI Smart Grid Coordination Group describes in the sustainable process document 5 high level categories of possible EV related Smart Grid use cases, namely:

- WGSP-1100 Uncontrolled charging
- WGSP-1200 Charging with demand response
- WGSP-1300 Smart (re- / de) charging
- WGSP-1400 Ensuring interoperability and settlement
- WGSP-1500 Manage charge infrastructure.

The Smart Charging use cases can be fit mainly in category WGSP -1200 and WGSP-1300.

WGSP-1200 describes demand response with signals. The idea is to use price signals or other incentives to influence the customer.

WGSP-1300 describes both, smart recharging and smart discharging. Sometimes the optimization has to consider conflicting (contradictious) objectives. However, the construction of an EV infrastructure must be done in a cost-effective way. This also means balancing the energy demand (charging requests) with available supply and grid capacity so to avoid unnecessary utility and grid investments. In addition it should also achieve the goal of a low-carbon EV mobility solution. RES, which are both centralized as well as decentralized, should be integrated.

Examples of WGSP Use Cases can be found at [93]. The picture below with an overview of EV charging is taken from this document:

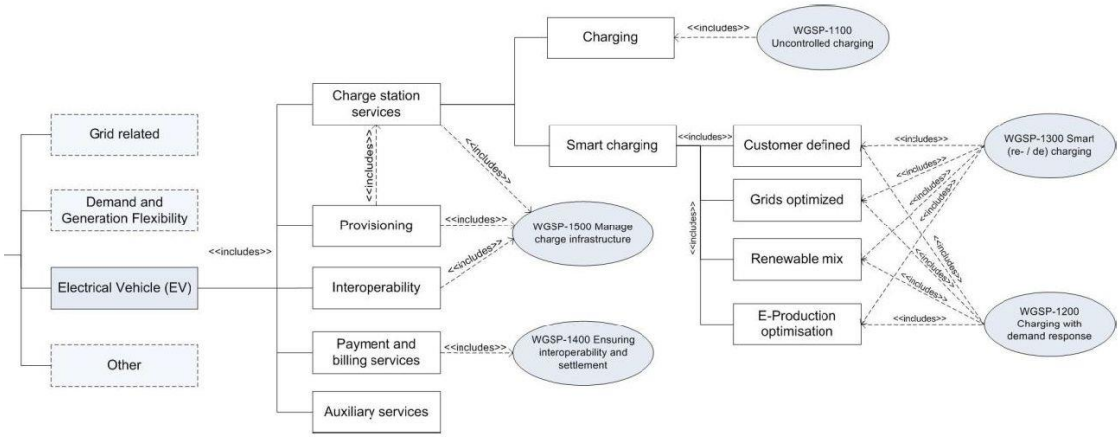


Figure 55 EV charging overview

4.7.1 Use Cases from eMi3

Under the umbrella of ERTICO – ITS Europe, the E-Mobility ICT Interoperability Innovation, eMI3, is an open group of significant actors from the global Electric Vehicles

market who joined forces to harmonize the ICT data definitions, formats, interfaces, and exchange mechanisms in order to enable a common language among all ICT platforms for Electric Vehicles. In this context eMI3 defines two Smart Charging processes in the eMI3 standard v1.0 [89].

Smart Charging with CEMS

The Smart charge with CEMS Use Case Element features the definition and specification of the different interactions occurring for providing Smart Charging features with a CEMS (Customer Energy Management System). CEMS can be both used by end consumers and professionals (building manager, factory manager).

Lean Smart Charging via OEM Backend

Lean (Smart) Charging describes charging at home (or semi-public) applying a charge plan (CP) provided by the SCP (Smart Charging Provider) via the existing online connection OEM BE to EV. Thus simple EVSEs w/o communication to an EVSE Operator can be used.

4.7.2 Use Cases from the Green eMotion project

The Green eMotion FP7 project compiled a variety of Smart Charging related use cases [88]. The description of these use cases can be found in deliverable 3.6, the use cases are summarized in the following list:

- 1572: UC Reduce Charge Power by DSO
- 1596: UC Peak load threshold on a substation
- 1597: UC Peak shaving
- 1598: UC Aggregated EV charge overview by the DSO
- 1599: UC History of EVSE use
- 1601: UC provide balancing capacity
- 1602: UC flexible load for congestion management
- 1604: UC Vehicle to grid signal
- 1605: UC Reserve and activate ancillary services

4.8 Summary

Chapter 4 and 5 are summarized together according to the explanation provided in the introduction to the Chapter 4.

Summary can be found in Chapter 5.6.

5 VEHICLE TO GRID

5.1 V2G concept

Vehicle to Grid (V2G) technology allows for the bi-directional sharing of electricity between Electric Vehicles (EVs) and Plug-in Electric Hybrid Vehicles (PHEVs) and the electric power grid [96]. This technology turns each vehicle into a power storage system that can be used by the network operator to increase power reliability and the amount of renewable energy available to the grid during peak power usage (according to [97]). V2G could provide regulation services, replace spinning reserves, or replace peak generation units (see [97]).

The concept of using the EV infrastructure for peak load and ancillary services, thereby allowing the energy to (also) flow back from the EV (battery) towards the electricity grid, is based on the following three assumptions:

1. an EV is equipped with a battery of significant capacity,
2. although possibly constrained with a minimum SOC level(s) at a given moment(s), such battery can be used as an electricity buffer while the EV is not driving,
3. the driver/battery owner is rewarded with an incentive of some kind for hooking up its EV to the grid whenever feasible. This incentive shall (at least on average) compensate the extra battery depreciation as a result of the services provided.

A major constraint for enabling V2G related services is that V2G capable EVs shall be connected to the electricity grid through a bi-directional power converter as soon as these are parked. In this context it is worth mentioning that a vehicle is typically standing still more than 90% of the time.

It is presumed that EVs will gradually replace the traditional vehicles. Although in the coming years only a part of the vehicles will be replaced by EVs, the number of batteries “connected” to the electricity grid is expected to increase tremendously. As an indication: a fleet of 100.000 connected EVs could provide 1000 MW of geographically-dispersed power, with the potential for primary regulating power.

5.2 Available or demonstrative products

AC/DC power converters for both charger types (on-board charger and external charger) are currently designed to enable energy flow in one direction - from AC to the battery. The power converter controlled externally by its active power will create the controlled load, which will have an active impact on the network load. This solution used in a V2G application was described by [98]. A system accepted by the Electric Reliability Council of Texas to manage the charging process of electric vehicles (trucks) was then prepared and demonstrated. Its high-level goal was to ensure a stable grid operation. When any deficiency of generated power and decrease in frequency occurred, the demonstrated system stopped the charging process immediately thus improving power balance.

There are numerous initiatives referring to the V2G projects and demonstration activities around the world (Grid On Wheels, EDISON Project, Project Plug-IN, U.S. DOD V2G Demonstrations, SPIDERS, MeRegio Mobil, Zem2All Malaga, Chrysler V2G Demonstrations, Green Crossover Town, Maui Smart Grid Demonstration Project, eV2G). Two most important are shortly described in Chapter 5.2.1 and 5.2.2.The known technologies allow us to build a bi-directional AC/DC power converter, which can send energy from AC network to the battery and collect energy stored in the battery to send it to the AC network. The power converter externally controlled by its active power and connected to the battery will create controlled energy storage. This solution used in a V2G application is the subject of various papers written at the University of Delaware, see [99], [100], [101], [102].

First tests of the EV adjusted to work in the V2G regime began in 2007 in a Toyota vehicle, now tests are performed in Honda and Nissan.

5.2.1 V2G demonstrations at University of Delaware and associated products

The University of Delaware has done extensive research within V2G technology. Their demonstrations were based on the VSL (Vehicle Smart Link) and supported by aggregation software which have both been developed by the university. The VSL solution is a set of embedded circuits that allows for communication between the vehicle and grid and can be used to invoke V2G services. The solution is marketed by NUVVE [103] outside of the US.

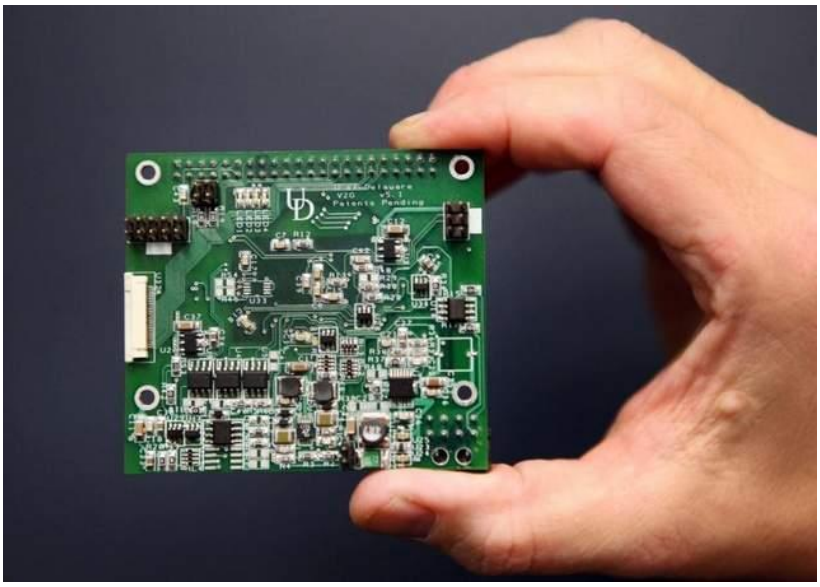


Figure 56. VSL controller for V2G

First vehicles used by University of Delaware were a fleet of converted Toyota Scions (Figure 57 right), later a larger fleet were provided by BMW AG (Figure 57 left).

Both these fleets of vehicles have been equipped with technology from AC Propulsion [104], a manufacturer of battery and propulsion systems.

Figure 57. (left) BMW Mini (right) Toyota Scion

The AC 150 power electronics unit supports the vehicles bi-directional power capability with up to 20 kW in one phase. The equipment can both supply power while grid-connected and in islanding mode.

The AC 150 has a set of digital interfaces that allows controllers, such as the VSL, access to the operation of the charger and power converter of the vehicle.

Figure 58. AC-150 Gen-2 EV Power System

The university has developed an aggregation server in order to coordinate the vehicles (dis)charging behaviour and has demonstrated how electric vehicles can be used to provide ancillary services. Specifically, the university has provided regulation services within the PJM area. PJM is the largest Regional Transmission Organization (RTO) in the states and the university is paid a capacity payment for participating in the market.

The most recent vehicle OEM cooperation UD has engaged with Honda where V2G is demonstrated using the Accord Plug-In Hybrid.

5.2.2 V2G demonstrations and product by Nissan

As part of their Zero Emission strategy, the Nissan Motor Company has launched a number of projects and initiatives around their battery-based vehicles.

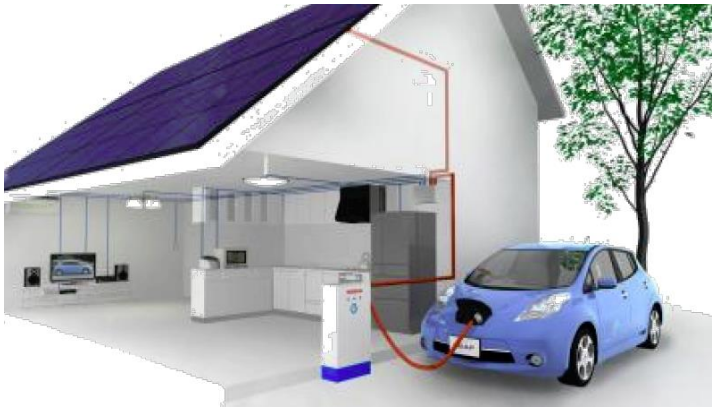


Figure 59. Leaf To Home

In Japan, Nissan has launched the V2H (Leaf to Home) system which went on sale from August 2012. This technology has been aimed at peak shaving, PV charging and emergency backup. The system relies on a special bi-directional charging station that connects to the DC outlet of the Nissan Leaf. The station also includes a 10 kWh battery that can serve as a buffer for PV production.

The Nissan e-NV200 van can provide power to loads directly connected to the vehicle. This could, among other things, be used to recharge battery-based power tools for electricians and technicians.

5.3 V2G functionality

The EV infrastructure will be used in the power system operation when all actors responsible for the cooperation will be interested in its effects. The scope of this cooperation, i.e. the functionality of V2G application, depends on the features of AC/DC power converter.

Uni-directional AC/DC power converters give a limited functionality to a network operator. The system operator may use an on-board charger and uni-directional external charger with AC/DC power converter as an element of the automatic load shedding system. When the power deficiency in the system occurs causing the decrease of frequency, under-frequency relay may shut down the power converters and pause the charging process. For the system operator this function may be particularly effective for quick improvement of the power balance, if fast high power charging is stopped. Effects of a slight delay in the charging process, which is resumed after the operator is able to control the disturbance, should be omitted.

Bi-directional AC/DC power converters provide the V2G application a wider scope of support for the power system. Rather than build, exploit and maintain the existing pumped-storage hydroelectricity, the power system operator (TSO) may use EV batteries connected to the supply system by bi-directional power converters as a distributed power plant and thus obtain power balance in the system. To achieve this, the operator must manually control the load of power converters by a respective information system.

The following shows a demonstration done in the Danish EDISON project where a V2G enabled Toyota Scion is used to provide the “secondary reserve” service used by the Danish

TSO. The secondary reserve signal is a MW value sent from the TSO to a group of providers and is positive or negative depending on the need of either up or down regulation.

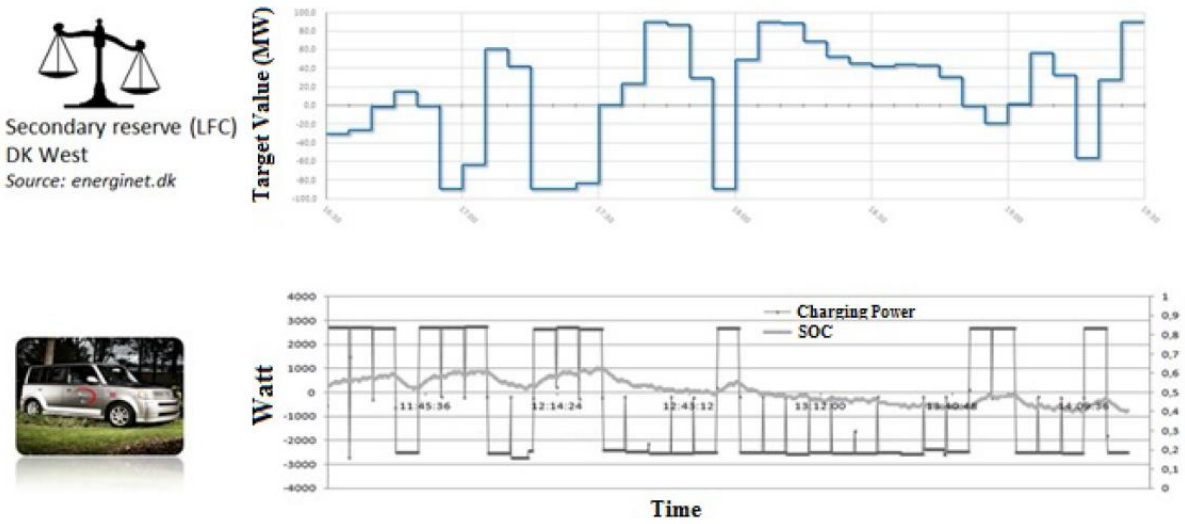


Figure 60. Demonstration of secondary reserve service used by TSO [94]

It can be seen from the figure that the EV precisely follows the aggregated regulation signal. The regulation signal in question represents a period with many fluctuations with a close to equal amount of up and down regulation periods. This has a positive impact on the State-Of-Charge (SOC) which stays close to 50 percent throughout the whole period.

The network operator (DSO) may use EV batteries to balance the network power or correct power flow. The operator must therefore control battery power converters, which are currently connected to its network, and in order to correct power flow the operator must know the site where each battery is connected to the network. Where power converters must be controlled by both TSO and DSO, they must build a common control system having a target hierarchy in mind.

Effective use of the battery requires delivering the following information to the operator:

- site of connecting battery to the network (site of connecting the battery power converter),
- nominal power of the battery and power converter assembly,
- value of energy transmitted from the battery to the system, considering the limitations specified by the EV user,
- value of energy the battery may collect from the system considering the limitations specified by the EV user,
- based on the foregoing information the operator makes a decision and sends the following information to the battery power converter:
    - value of power of a power converter connected to a particular battery,
    - power direction.

The owner of the battery connected to the bi-directional power converter may get economic benefits during EV stops at any site by charging the battery with cheap energy collected at a night rate and selling it at the peak of system load in any other site. The power converter's work schedule is determined by its owner who maximizes a profit resulting from

the selected rate. The owner may also give the battery to the operator to use it against a fee and during the term specified in the agreement. In this case the operator controls the power converter, while the owner makes additional profits from various rates of energy exchanged with the supply network as requested by the operator.

Energy involving financial settlements must be made based on certified energy meter installed by the owner of the supply network to which the battery power converter is currently connected. Mobility of the EVs battery may complicate the settlement process. Settlements should be therefore made by the centre for financial settlements, including national and international roaming.

The centre must be provided with the following information:

- battery and owner identification number,
- battery localization,
- connection time,
- counter indication for all rates following the connection of the battery power converter to the supply network,
- disconnection time,
- meter indication for all rates following the disconnection of the power converter.

A smart meter transmits information to the centre. This transmission is initiated by connecting and disconnecting the EV from the socket behind the meter – socket with IT link.

The owner of EV and battery with bi-directional power converter connected in the garage to the home system may have an emergency power source (emergency power system). Opportunities offered by EV and PHEV may be particularly attractive to rural recipients during power shutdowns because of various failures, especially during winter. To serve as an emergency power source, the power converter must be equipped with the islanding function. After turning off the switch separating home installation from the supply network, the power converter must change its mode of operation to a voltage source in order to balance active and reactive power and maintain the nominal voltage value and frequency in the islanding network (installation).

Furthermore, the possibility of using a bi-directional AC/DC power converter built in the PWM technology to work as an Active Power Filter is worth mentioning. Connected permanently to the power network as an external charger with its respective controller, it may function as a passive power compensator, high harmonics filter and a load balloon for the network.

Finally, the EV owner may have a need for electric energy in places where an access to the general electricity grid is not possible or practical. Access to the battery energy for applications other than driving could be a service to the EV owner.

In this Vehicle-To-X (V2X) service, energy is drawn from the vehicle battery directly to a connected load. Examples of applications can be vehicle-to-vehicle and vehicle-to-electric tools.

Table 17 shows functions essential for the power system operation which may support the EV infrastructure depending on its configuration.

Table 16. V2G functionality

		Battery			On-board charger		External charger	
		In a car, embedded permanently	**In a car, replaced at the station**	**At the gas station waiting to be replaced**	**AC/DC power converter**	**bi-directional AC/DC power converter**	**AC/DC power converter**	**bi- directional AC/DC power converter**
Charging location	Garage	X	X		ALS	CtrlStorage EPS	ALS	CtrlStorage EPS APF
	Car park	X	X		ALS	CtrlStorage	ALS	CtrlStorage
	Charging station at the motorway (fast charging)	X					ALS	
	Charging station at the motorway			X			ALS	CtrlStorage

ALS –Automatic Load Shedding – switching off the charger in case of sudden power shortage in the power system and frequency decrease

CtrlStorage –Controlled energy Storage – system consisting of EV battery and bi-directional PWM power converter, controlled remotely by the system operator. CtrlStorage can operate similarly to micro pumped-storage units.

EPS –Emergency Power System – system consisting of the PWN power converter, that operates as the voltage source stabilizing the frequency and voltage in the load node

APF –Active Power Filter – shunt active power filter consisting of PWN power converter, that operates as current source and compensates reactive power, reduces asymmetry and mitigates harmonic current in the power system

5.4 V2G perspectives

Technical, IT and financial aspects will determine the potential of possible common use of the EV infrastructure for V2G services. At the moment of writing this report, a combination of these aspects are hampering a commercial roll-out of V2G.

One technical/commercial issue is that offering V2G related services will imply extra cycles for the battery of the involved PHEVs or EVs. With the current combination of battery prices (consumer prices ranging from 200-500€, including VAT) and typical battery durability (in access of 3000 80% DoD cycles) it is not attractive to provide services that will result in deep SoC cycles (see Figure 13, [105]). The introduction of new battery technologies and/or significantly lower kWh prices for batteries might change this.

Presuming the currently used (PH)EV battery technologies/chemistries, services that typically involve only shallow DoD cycles are expected to become economically feasible first. This means that (PH)EV involvement in offering primary regulating power is expected to be amongst the first commercially attractive V2G applications.

The purchase of EVs and giving its storage to the network/system operator may be also stimulated by providing subsidies to the EV owners and advantageous charges for the lease of EVs acting as controlled energy storage. The grid operators may contribute to these subsidies by paying the avoided costs associated with the equivalent system storage (such as spinning reserve facilities). In the long run profits from trading energy, collected and transmitted with a respective difference in fees based on different rates, may become the basis for the incentive to the EV owner.

To become broadly accepted, such a vehicle operation and financial settlement must be implemented in a very user friendly way. This means that it must be supported by the information system in order to minimize the burden for the EV owner, and be effectively used, irrespective of the vehicle localization and supported V2G services. The ability of the EV to cover a planned/desired distance is most important for the user. Whenever the system fails to provide enough electric energy in the battery of the (PH)EV to drive a planned/desired trip, the willingness of the EV driver to participate in any demand-side response program, peak-load power services and/or ancillary services is expected to degrade rapidly.

The EV user's activities should be limited to loading the relevant data to the on-board computer (directly by HMI or by the smartphone's app) and connecting the EV charging cable to a respective socket. Preferably, the EV user's activities are limited to sharing his/her agenda. The on-board computer shall in that case plan the trip(s) in enough detail to be able to determine the (worst-case) energy demand and the corresponding constraints on the SoC as a function of time. The on-board computer, together with the system of monitoring the battery condition, shall transmit the SoC constraints through an IT link to the charger (on board or external). This information, complemented by the charger and battery constraints, shall be transmitted to an EV charge management system/aggregator/service-provider, which offers its power reserve services to the involved DSOs. Such EV charge management system/aggregator/service-provider will either directly or indirectly (e.g. via a pricing strategy) control the contracted EV chargers and will also be responsible for compensating the EV owner for the offered services.

V2G applications may have the highest service range if they use bi-directional AC/DC power converter built in the PWM technology. With respective controllers such power converter may be used in all situations shown in Table 16.

Looking to the nearest future, it can be concluded that the role and the importance of V2G solutions will depend on technical improvements not only of AC/DC power converters, but also of batteries and charging stations. If today thinking of reverse energy flow (i.e. losing charge for the user) could appear quite challenging for an EV that guarantees only 100-150

km after 8 hour charging, this should not necessarily be the case for EVs that will have more battery capacity and faster ways of charging. In that case, indeed, losing some percentage of the battery charge to provide useful and remunerated services to the grid will undoubtedly represent a smaller issue. The latter is –of course- already the case for PHEVs that can always fall back on the energy from the range-extender.

Also the charging procedure and future business models will remarkably affect the V2G possibilities. Credit card-paid, ten minutes long and high powered charging procedures will probably decrease the leeway for V2G solutions, while contract-paid, slow charging at home/office will guarantee more flexibility to the grid operator.

Although not explicitly considered in this section, it is also worth consider briefly the perspectives of the "Vehicle to Home" (V2H) concept. With the V2H concept it is possible to (temporally) satisfy the electricity demand from a household through the battery of an EV. This may help alleviating consumption of power in peak periods, may help in maximizing the use of privately produced renewable energy and may serve as backup power supply during major power black-outs. This concept is related to the V2G concept because similar capabilities from the (PH)EV's battery charger will be required. Moreover, it is expected that a (PH)EV that would support V2H applications would also comply with the standards that will be required for V2G applications (such as IEC 15118), as little additional costs need to be incurred for this purpose.

At the moment of writing this report, owners of PVs in the West-European countries are typically allowed to NET-out their produced electricity (including energy taxes) with electricity used. It is expected that (at least in a few countries) this will change in the near future, and PH owners are expected to get significantly less for their produced energy when delivered back to the grid. In that case it may become appealing to use a (PH)EV for storing the excess of energy and using this energy when otherwise energy from the grid would have been required. In that case there may be a business-case for EV owners that use privately produced PV (or wind) energy. This may translate into business opportunities for EV OEMs, offering a V2H/V2G capable on-board charger. When this happens, it is considered to be an enabler for V2G related services as it will overcome the chicken-and-egg problem around V2G capable vehicles and V2G capable infrastructures.

5.5 Interoperability problem avoidance according to the PowerUp 7FP project achievements

According to the recent changes in European approach to the power system management in case of Distributed Generation and Renewable Energy Sources it is essential to replace uncontrolled operation of all units and systems such as Distributed Generation, Renewable Energy Sources, active loads, Demand Side Response by coordinated systems with the right set of services improving market competitiveness and supporting the grid operation (Ancillary Services). It is therefore essential for the viability of all developments in the mentioned fields to provide better coordination between electricity production and demand side. The Vehicle-to-Grid (V2G) interface concept is an essential mechanism for such coordination.

Regarding the automotive aspects of electric vehicles, their limited driving range is one of the biggest deployment challenges. For mitigating this restriction, it is essential that

owners should be able to recharge their electric vehicles not only at home but also at their destination, namely at parking garages near their offices or near train/subway terminals. The Vehicle to Grid (V2G) interface concept is a mechanism for supporting this paradigm of nomadic electricity consumers. However, it raises questions about the architecture of measurement and billing components, as well as the involved value chains. A suitable design of the V2G interface shall support nomadic electricity consumption under any foreseen arrangement of the billing architecture or value chains.

For achieving the anticipated V2G-enabled benefits, the PowerUp project has developed and validated the V2G interface. PowerUp has also progressed through a full development cycle of physical and link-layer V2G interface specification, protocol design for scheduling of recharging and for accounting control, prototype implementation, conformance testing, integrated field trials, and standardisation.

PowerUp has contributed its results to the following highlighted standardisation activities:

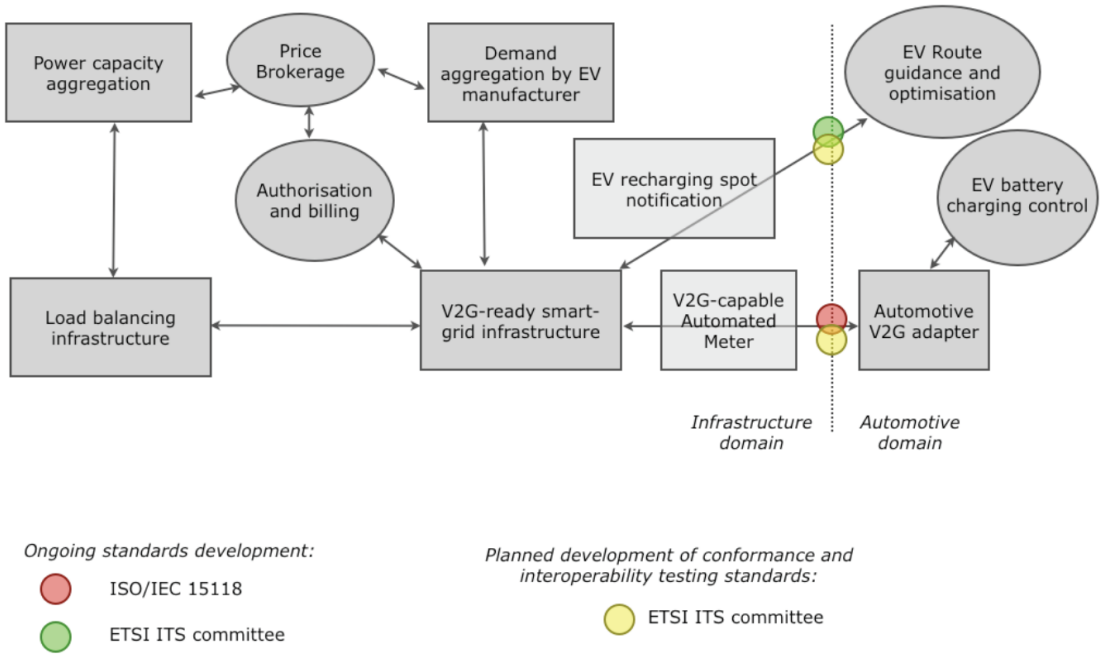


Figure 61. PowerUp related standardisation activities [106]

5.5.1 Achievements of PowerUp in V2G from the COTEVOS perspective

The PowerUp achievements can be summarized as listed below and presented in Figure 62 [108] :

- Aligning V2G procedures to match automotive procedures; main investigated issues are concerning DC charging and power re-negotiation
- Automotive integration of the V2G system (focus on AC and DC charging)

- Development and standardization of EV-specific extensions to the DLMS smart-metering protocol model
- Development and testing of UPA modems for V2G interface, along with two types of PLC couplings and filters
- Development of a control unit for identifying which vehicle is connected to which charging spot
- Development of HMI for recharging control of buses, passenger cars and vans
- Development of HPGP/G3 media conversion
- Development of SNMP messages for link control (alternative to the Pilot Control Function, without the need for dedicated pilot line)
- Development of test cases for validating conformance and interoperability with the ISO/IEC 15118 protocols
- EV Load Balancing algorithm development
- Interface development between the Smart Meter and the EVSE
- Proving that coexistence between HomePlug-GreenPhy and UPA technologies is feasible
- Specification of power re-negotiation procedures
- Specification of the V2G architecture for interoperability with existing smart-grid systems [107]
- Development of V2G Interface specifications between the electric vehicle, the local smart meter, and ITS service providers (DLMS/COSEM) together with proposals of specifications for the enhancement of existing smart metering protocols
- PLC and 5.9 GHz wireless media for the V2G interface, with real-time switch-over possibility between them
- V2G interoperability testing capability; relevant for compatibility of follow-up multivendor products

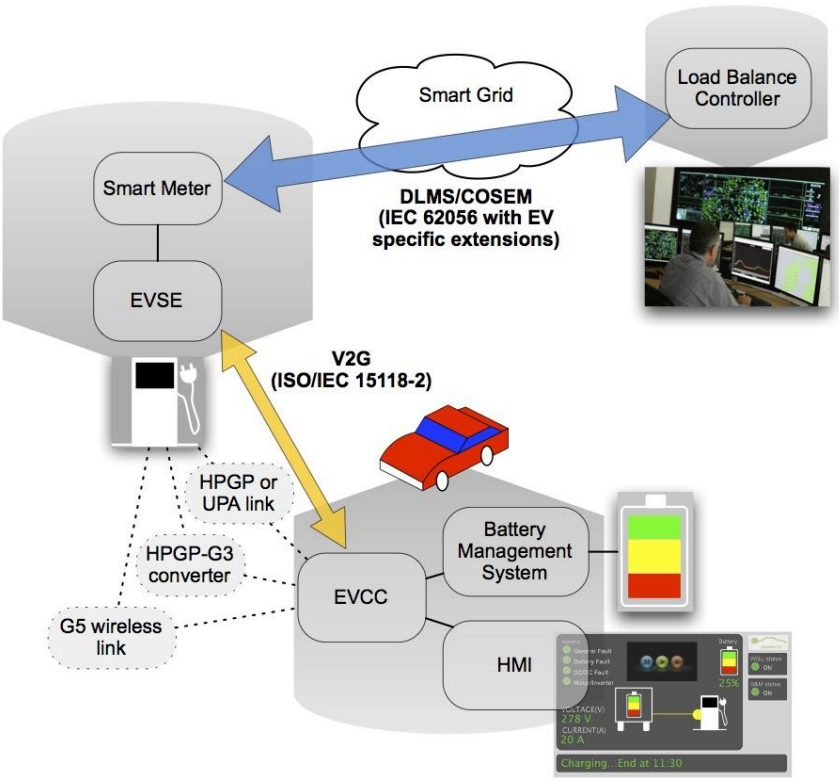


Figure 62. Overview of the PowerUp achievements [108]

In fact, all achievements of the PowerUp project contribute to the avoidance of the interoperability problem in case of e-mobility. Specification of the interfaces, development of a series of updates and inputs for e-mobility subsystems, aligning procedures in the field of V2G are somehow a step forward. However, the most important for the interoperability issue, from the COTEVOS perspective is:

- PowerUp development of V2G architecture [107]
- V2G Conformance Test Specifications [109] for the V2G interface; Protocol Implementation Conformance Statements (PICS), Test Suite Structure and Test Purposes (TSS&TP) and Abstract Test Suite (ATS) by following the ISO 9646 testing methodology and ETSI recommendations and relying on the V2G base specifications from the standard ISO/IEC 15118-2
- V2G interoperability testing framework [110]

5.5.2 Interoperability Testing Framework

PowerUp project has progressed much on the interoperability testing, however it is only a starting point as many aspects are still not solved. It has developed an interoperability testing framework for the Vehicle to Grid (V2G) interface, mainly based on the standard ISO/IEC 15118-2 and PowerUp V2G architecture (Figure 63 and Figure 64), which can be used for further interoperability test specification development also in COTEVOS project.

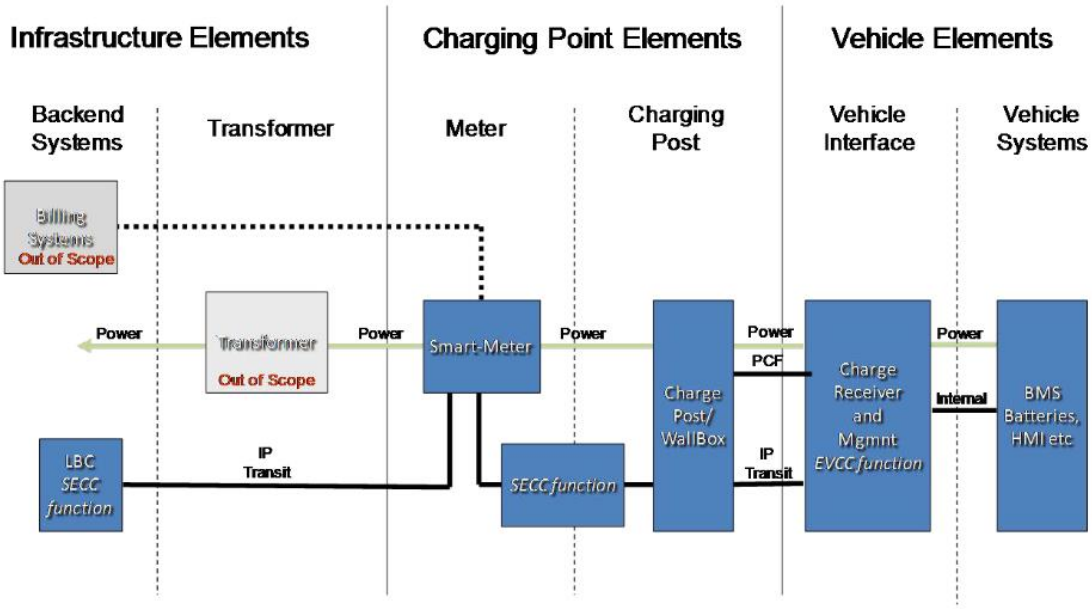


Figure 63. Abstract of PowerUp System Architecture [107]

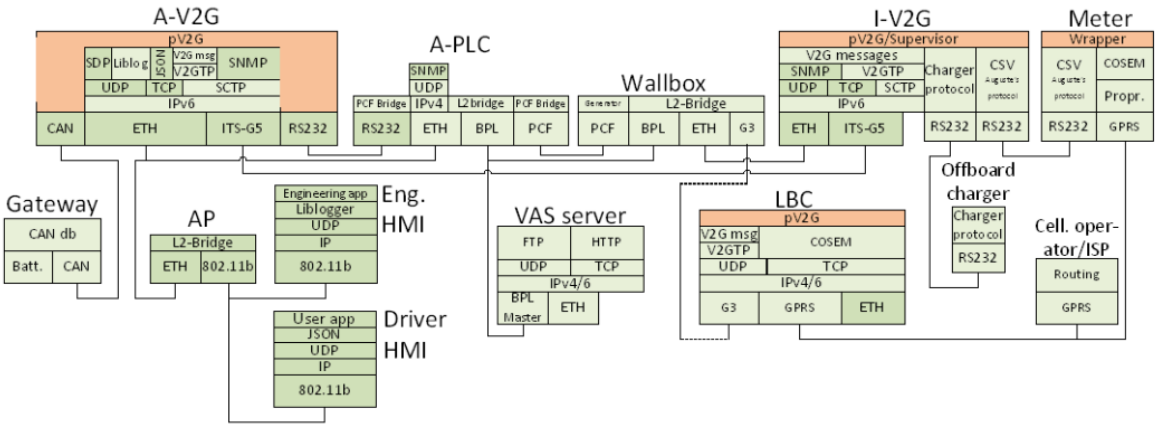


Figure 64. PowerUp System Architecture [107]

Interoperability testing is usually considered as the next step in the logical process of the testing cycle. Essentially, interoperability may be viewed from two perspectives:

- For a manufacturer, this is the activity of proving that end-to-end functionality between (at least) two communicating systems is as required by those systems' base standards.
- For a consumer, interoperability means the ability to acquire the relevant terminal device and begin to use it with another device implementing the same technology.

The purpose of interoperability testing is not only to show that products from different manufacturers can work together but also to show that these products can interoperate using a specific protocol. In certain situations some limited conformance testing with extensive interoperability testing may be sufficient.

Multi-vendor compatibility is crucial for the success of V2G technology, so that the recharging of any fully electric vehicle brand could be controlled by any electric network in the European Union.

5.5.2.1 **Overview of the V2G Interoperability Testing Framework**

PowerUp interoperability testing framework for the V2G interface is based on the standard ISO/IEC 15118-2, V2G architecture [107] and demo stories (test cases) [110] developed in the project. The methodology assumes 4 steps [110]:

- Identification of candidate Equipment Under Tests (EUTs)
- Identification of Test Scenarios
- Specification of Test Bed
- Development of Test Descriptions

Particularly developed testing framework considered as Equipment Under Tests the A-V2G and the A-PLC on the vehicle side (A_EUT), and the Wallbox and the I-V2G on the infrastructure side (I_EUT). Names refer to the V2G architecture depicted in the Figure 64. Additional Equipment Under Tests defined in the PowerUp is presented in the Figure 65. Descriptions and abbreviations come directly from the PowerUp project documents.

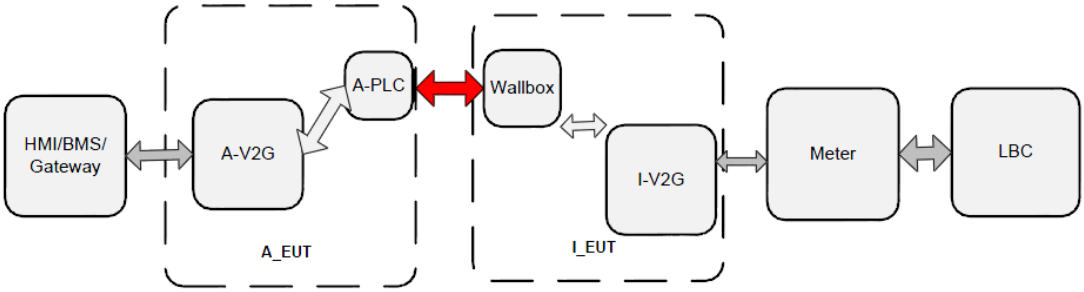


Figure 65. PowerUp EUTs

5.5.3 Field test findings

The PowerUp developments have been extensively tested and proven at two independent trial sites, with two completely different charging regimes and baseline equipment to be integrated with.

There have been a huge number of learnings during this process; from small issues such as the types of connectors that individual manufacturers prefer, through medium ones such as the differences between inductively and capacitively coupled PLC to very significant ones such as proving that the structure proposed in ISO15118 is applicable both to its intended domain (AC charging) and beyond it to the high current DC charging environment [111], [112].

5.6 Summary

According to the introduction to the Chapter 4 (Smart Charging), problems such as Smart Charging and vehicle to grid are permeating each other. Therefore, following chapter sums up both V2G and Smart Charging.

Well designed and implemented procedures for the Smart Charging can provide benefits for:

- EV battery, if procedures take into account charging parameters affecting battery lifetime
- EV user, if procedures support following the charging schedules with minimization of the electricity cost (from the network, during charging)
- Electricity grid, if the charging is controlled for avoiding network branches overload
- Power system, if multiple charging is stopped temporarily in order to maintain the power/energy balance in the system and prevent from outage

Similar procedures applied for the V2G can provide even higher benefits for:

- EV user, who can gain the additional profit from the energy trade – charging the EV battery during the off-peak and discharging in the peak
- Electricity grid that can be prevented from the overloads due to the peak shaving, without load shedding
- Power system, while large number of the EVs, controlled for V2G services, reaches the cumulative power of the micro pumped storage unit and supports the power system operation

Procedures must take into account priorities in the fulfilling the control objectives.

Providing the Smart Charging requires controllable uni-directional charger. In case of the V2G, controllable bi-directional power converter is indispensable. For both services and technical solutions for charger and bi-directional inverter, it is advisable to deploy 3-phase PWM invertor, as it introduces low disturbances to the electricity network.

Designing the bi-directional charger as the on-board, allows for the use of simpler and less expensive EVSE. It should facilitate introduction of the large number of EVSE. As a result, the probability of the Smart Charging and V2G use, increases. Additionally, large penetration of the EVSE allows for a selection (by the system operator) the network nodes, where the services are needed most.

The on-board bi-directional charger design, simplifies the communication between EV and EVSE. The only information that is sent reflects to the service (Smart Charging, V2G). Information about the battery, preferred charging pattern etc. are fully internal.

6 USER EXPECTATIONS FOR FUNCTIONALITY OF CHARGING SYSTEMS – SUMMARY OF STUDIES BASED ON QUESTIONNAIRES

6.1 Assessment of functionality of charging systems from user point of view

Today and future EVs are designed with a wide range of specifications to satisfy different customer preferences. Their impact on power grid operations will heavily depend on their market penetration [58]. Currently EVs are equipped primarily with lithium-ion batteries, with energy capacity range from 16 kWh to 80 kWh for high performance EVs. Pure EVs clearly show different consumption behaviour from plug-in hybrid electrical vehicles (PHEVs) which use conventional fuels, as well. They have smaller batteries compared to the pure EVs (ranging from 4 kWh up to 16 kWh) and their conventional fuel engine eliminates range anxiety. In the presented research we are focusing on the pure EVs, since these users are dependent of the charging system and are therefore expected to be more critical about its functionality. Charging EVs is rather a slow process, as even fast charging takes at least half an hour for charging a depleted battery to 80% SOC. A research article revealed that running out of "energy" on a highway, or in a risky situation, is the most important reason for people considering the purchase of an EV not to do this [62].

The average driving distance is 38 km per day in Norway [59], 39 km per day in Germany [60], 35 km per day in Slovakia/Austria [61] and 40 km in US [64]. The need to recharge EVs frequently and for an extensive period of time imposes drivers with extra constraints that are linked with the desired vehicle range. An Accenture study [69] with 7003 respondents from 13 different countries, who had no experience with electric cars, has revealed that:

- the availability of a home charging point is very important;
- 50% of the respondents indicate the need to have a fast charging option;
- 49% of the respondents wanted to have the ability to charge at work or in public parking slots;
- 65% of the participants wanted to charge their car at home;
- 13% on “gas” stations;
- 11% in a street;
- 6% in working parking lots;
- 5% in public parking lots.

The corresponding overview is displayed in Figure 66:

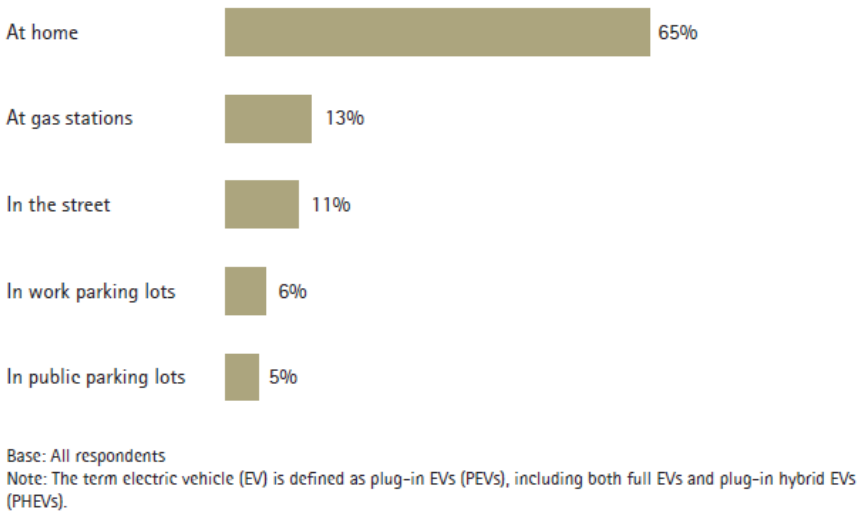


Figure 66. Accenture end-consumer survey on the electrification of private transport

6.2 Home charging

A study conducted in England with 40 non-commercial drivers driving an EV for one week showed that the majority of the drivers considered the charging process as straightforward and convenient. One of the most appreciated features was the ability to recharge the vehicle at home. Most of the private users use home charging devices for charging their e-cars [65]. The EV driving distance is enough for most of customer's daily needs. A lot of EV users charge their cars several times per week. Most of the users don't have problems with their home charging solution. Some of the progressive EV users would appreciate more intelligent charging devices, allowing them to automate the registration, to (remotely) monitor the power consumption and to specify the charging profile (start time, duration, max. power [63].

After a trail period of 6 months in Berlin, 71% of the 80 MINI E drivers preferred recharging (at home or at a public charging sites) compared to refuelling at a gas station, and 87% agreed that charging was easy although. However 57% of the respondents found the charging cable cumbersome. Despite these positive aspects, some drivers experienced difficultly with lengthy charging times [66].

During a 7 day trial with 20 PHEV and 20 EV, some of the 40 drivers/respondents had a negative perception of the time it took to charge the EV (compared to the 5 min it takes to refuel a conventional vehicle). Participants perceived this time waiting for the car to charge as 'dead time', thus compromising the freedom of movement and the flexibility to 'take-off' [65].

Another pilot project and study included nine types of EVs, which were driven in the UK by 207 private drivers during a 3 months period. The study compared interviews before and after the trial period. Users were asked for their experiences with charging including differences between driving an EV compared to a conventional vehicle. In the first "pre-expectation" phase, the majority of drivers did not think that adapting to charging their EV would be a difficult task. After experiencing the EV charging-process related constraints for 3

months, significantly fewer drivers found the adaptation to the charging scheme of the vehicle easily [67]. The summary is shown in the Table 17:

Table 17. 207 user's pre-expectations and EVs user's experiences in 3 months UK trial

Level of agreement in percent to the questionnaire items.

Questionnaire statement	Time point	*N*	Disagree/strongly disagree (not important)	Neutral	Agree/strongly agree (important)	Sig
Recharging versus refuelling						
Adapting to charging the vehicle will be/was a difficult task	Pre	93	73	15	12	*
	3 m		88	6	6	
I prefer charging my car than going to a petrol station	3 m	135	3	12	85	
I would like a text to be sent to me when my car has reached full charge	3 m	103	13	28	59	
I would prefer an automatic charging system	3 m	135	14	30	56	
The time it takes to fully charge the battery has limited my use of the EV	3 m	135	54	12	34	
Recharging routines						
I typically recharge my EV at a regular interval	3 m	134	43	8	49	
I typically recharge my EV when the state of charge falls below a certain level	3 m	133	39	7	54	
I typically recharge my EV whenever I get a chance	3 m	134	35	10	55	
Public charging infrastructure						
Having a supportive PCI is essential for people with EVs	Pre	93	8	3	89	*
	3 m		15	12	73	
I can complete my daily trips without a PCI	Pre	74	7	17	76	*
	3 m		7	8	85	
I would buy EV in future if only place to charge was at home	3 m	103	30	9	61	
Environmental impact						
How important would CO_2 emissions be if you were to purchase a plug-in vehicle?	Pre	36	44	17	39	*
	3 m		3	5	92	
Renewable energy should be used to power EVs	Pre	91	5	18	77	
	3 m		5	18	77	
Widespread use of EVs would result in lower carbon emissions in the UK	Pre	91	6	2	92	*
	3 m		31	5	64	
I would be willing to pay more for a vehicle that I knew was less harmful to the environment	Pre	89	29	20	51	*
	3 m		11	15	74	

* Significant pre-3 month comparison at $p < .05$.

Also users found similarities between the ease of recharging the EV and recharging the other common appliances such as mobile phone or laptop. The simplicity of charging helped to shape a positive consumer perception of EVs. At the end of the trail period, users were investigated whether they preferred recharging at home or refueling on petrol station. 85% of the respondents preferred to plug-in their car at home, compared to refueling by visiting a petrol station. Respondents described convenience, cleanliness, independence, time and cost effectiveness, and not paying for the cost upfront for the preference of home charging.

Some of the users felt satisfied with the fact that they do not need to visit petrol stations [67]. These findings are similar to previous researches represented users experiences with charging like simple and convenient [65], [66], [68].

6.3 Public charging infrastructure (PCI)

In the pre-phase of a UK based trial with 207 private EV users it was shown that 89% of these EV users were expecting that a recharge of their EV using PCI would be required for fulfilling their daily travel needs. After 3 months this number was reduced to 73%. Drivers were also asked how many times during the trial they had used the PCI:

- 39% indicated: never;
- 47% indicated: between 1 and 5 times;
- 14% indicated: more than 5 times.

From the drivers that used the PCI at least once, the majority (78%) had difficulty finding a charging point and of those drivers 46% indicated that it was easy to use [67].

In the (earlier mentioned) 80 MINI E Berlin trial that lasted 6 months, 83,7% of the charging events took place at the drivers´ own private charging station and only 4,8% took solely place at a public charging station [66]. In the early stage of using an EV, users are charging whenever they can. After few months of using the EV the EV users have more confidence and experience in judging the remaining range, given the battery SOC.

The users perceived the slow public charging infrastructure as a psychological support for their energy needs in the case of a low battery state-of-charge. This anxiety is reduced even more by extension of the network of fast chargers [61]. Public EV charging is attractive for consumers who might be out and about running errands and require their EV's battery to be recharged [63]. As people indicated to drive mostly small distances each day, it can be sufficient to charge at public charging points at e.g. shopping centres, car parks at railway stations, parking lots of office building [49].

Workplace charging opportunity

The Electric Power Research Institute (EPRI) estimated that 54% of non-residential parking occurs at the workplace where the layover is often between 4 and 8 hours. This extended period where vehicles are standing still is the perfect time to provide EV owners with an extension in range. Workplace charging could provide EV owners an extra 15 – 70 miles of range depending on the SOC and available charging infrastructure. This matches well with the characteristics of typical commuters today, of which 90 percent drive less than 40 miles one-way to work [64].

Fast charging

70 % of customers say that charging for full EVs is too long. There is clearly a market to satisfy and fast charging provides opportunities for premium pricing [69].

Battery swapping

Accenture study also showed that 62% of the potential consumers prefer charging their battery, whereas 38% prefer swapping an empty battery for a fully charged battery [69]. Figure 67:

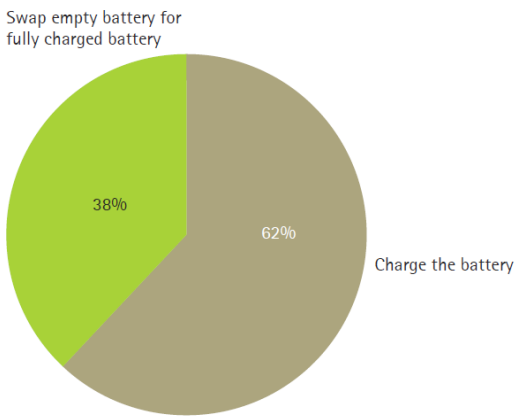


Figure 67. Customer's preferences between battery swapping and battery charging

Charging point operator decision when customer can charge

Participants of the Accenture survey were also questioned about possibility of allowing a charging point operator to determine when to charge the electric vehicle. 67% of the respondents answered that they don't prefer this option, as they want to charge whenever they want/need. 20% of the respondents accept this option only if they can decide about a predefined charging timeframes [69]. Figure 68:

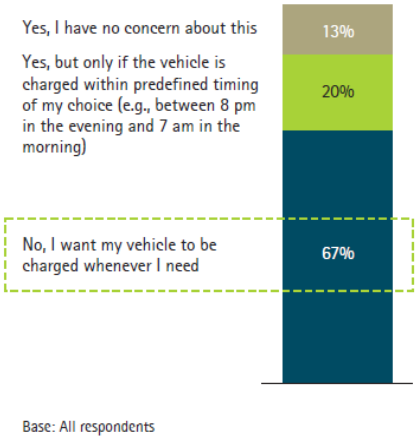


Figure 68. Customer's preferences in the determination of charging time by charging point operator

The Grid for Vehicles (www.g4v.eu) survey conducted on 1899 non-EV users/respondents in 8 European countries also investigated the interest in joining delayed charging schemes (off-peak times 22.00 – 06.00). Here the respondents answered positively, with an average of 5,74 on a scale from 1 – 7. Being afraid of not having the possibility to use their car at any moment in time is the most frequently given reason not to be interested. Faced with the option of having their battery partially recharged immediately, the options to charge 40 km (2 €), 80 km (2.5 €) or 120 km (3 €, full range) were almost equally preferred by the respondents, with a slight tendency for a full battery immediately.

Interest in the participation in vehicle-to-grid (V2G) initiatives is above average with 4.38 on a 1-7 point scale, with UK and Portugal showing highest interest. Compared to the interest stated for delayed charging schemes this is however a significant lower interest. Through a follow-up question regarding the reasons of not being interested to participate in V2G, it became clear that the low level of benefits that are expected to be received as a result of participation in such a scheme is the prime reason (45% of respondents). Offers to choose between 20 € or 60 € showed that a significantly higher benefit has a significantly higher impact on people and stimulates participation. 71% of the respondents that were interested in the V2G services also indicated that they would accept a minimum battery capacity of 120 km or less when their car battery is used for balancing the grid [49].

6.4 Customer's preferences in service providers

The Accenture survey also asked respondents which charging service operator they would prefer. The majority (79%) had the utilities operators in their top three list (see Figure 69). Traditional oil companies/gasoline and diesel service stations came out secondly in this

top three list. Retailers and local governments were in the top three list of half of the respondents [69].

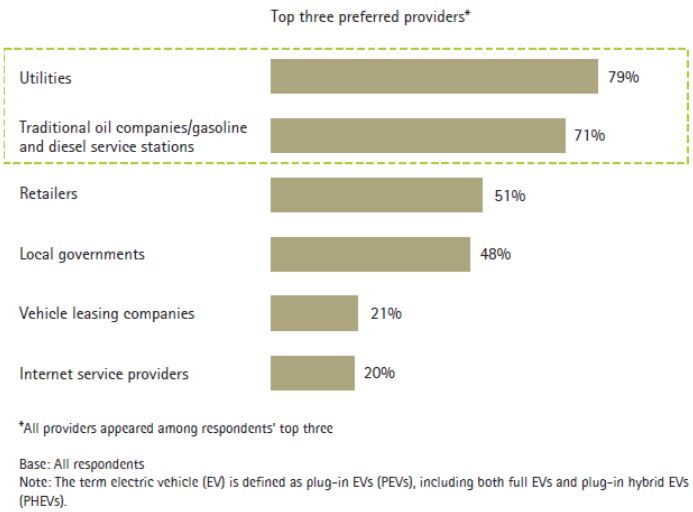


Figure 69. Customers in the Accenture survey were questioned about preferences in the charging operator

Charging payments

71% of the Accenture survey participants prefer to pay as they charge their vehicles, thereby using a credit or debit card. Less than a third would opt for a periodic bill. This could be a challenge for utilities and an opportunity for new-entrant charging service providers (see Figure 70). When the complexity of roaming networks for charging are taken into account, utilities' ability to maintain a consumer relationship at the point of charging looks increasingly challenging [69].

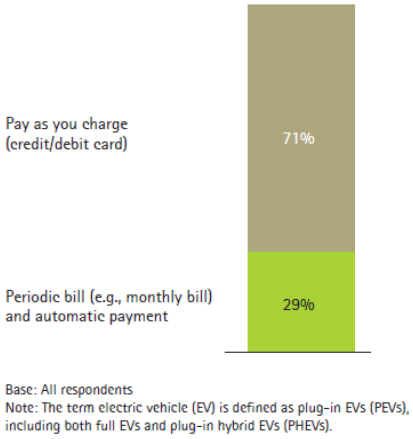


Figure 70. Accenture survey customers charging payments preferences

Preferred charging location

In the Grid for Vehicles survey (www.g4v.eu) respondents were questioned about their preferred charging location. The majority of respondents in all countries have a private parking place at home or at work where they would charge their car. In France and Germany,

most prefer to recharge their car only at their private parking place. Private recharging in combination with the use of public recharging spots is preferred by the majority of the respondents in Italy, Spain, the Nederland, Portugal, UK and Sweden. The majority of respondents, who don't have a private parking place at home or at work to charge their car, are in most countries afraid that they will not find a public charging place. The majority of users in Italy and UK without a private parking place expect that they will charge their cars on public charging points [49]. See also Figure 71:

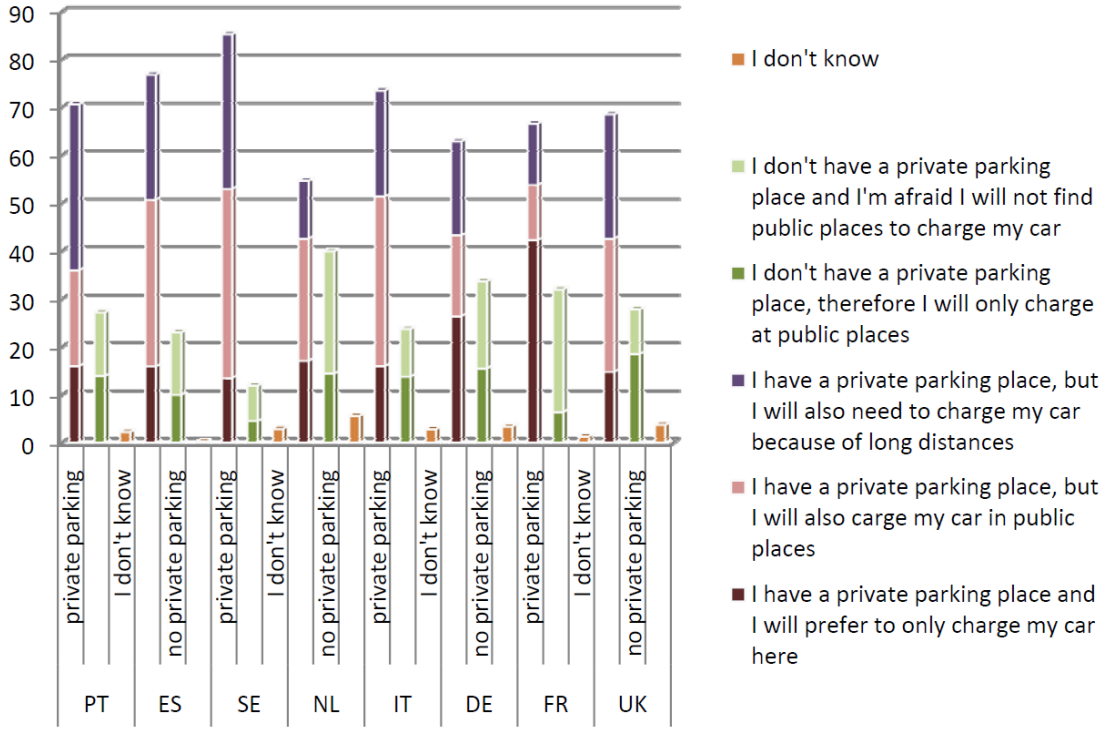


Figure 71. Preferences in charging location according to G4V survey

User's expectation on the charging time duration

Based on the Deloitte survey results [125] conducted with 13 000 individuals in 17 countries, customers' expectations are inconsistent with the current capabilities. Respondents were inquired about the longest acceptable time for fully charging a battery. The majority of the respondents expected electric vehicles to be recharged in two hours or less. See the results in Figure 72.

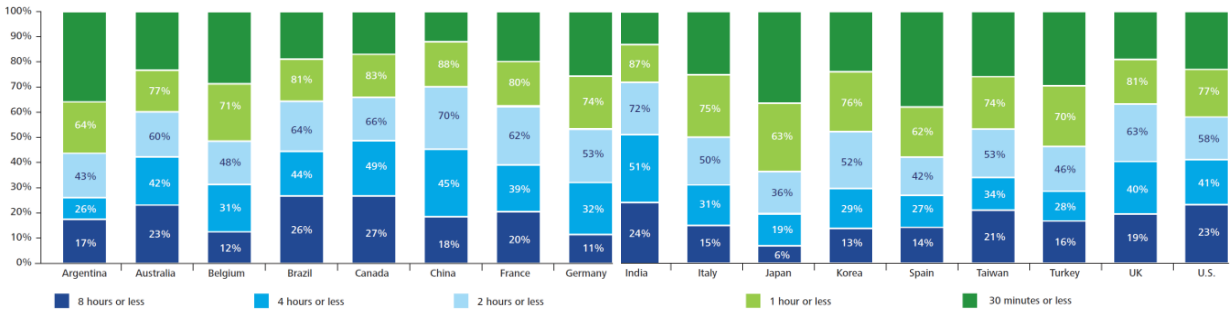


Figure 72. Deloitte survey - individual requirements for the full charging battery capacity

Respondents also expect new tools/apps to support the dissemination of information about charging. Users want to use smartphone connected to the vehicle by telematics where they can receive an indication on the state of charge of its battery in real-time.

The electric vehicle market research study in Canada conducted on 200 residents in the city of Guelph showed different results. In this study 24% of respondents require charging duration in the time 1-2 hours, 30% require 3 – 5 hours and 22% require charging time from 6 to 8 hours. The average customers charging time expectation is 4,3 hours to charge full battery capacity [63]. See the summary of these results in Figure 73:

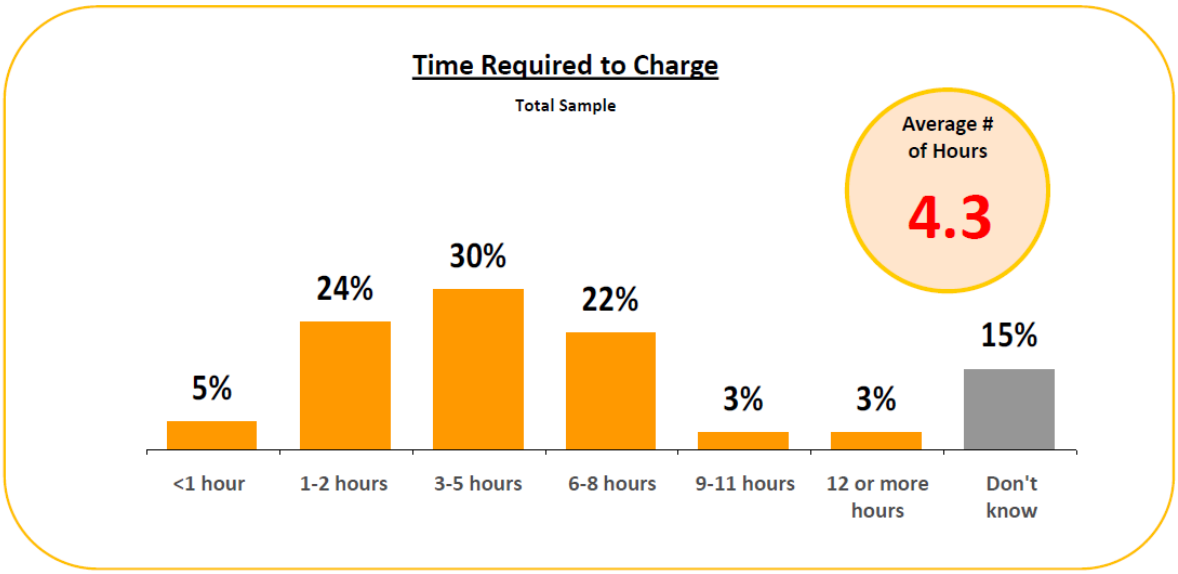


Figure 73. The residents' requirement on charging time duration in the city of Guelph in Canada

Charging times preferences

93% of the respondents in the Electric vehicle market research study in Canada prefer charging at home. 72 % of all respondents prefer charging somewhere between 9 pm and 8 am [63]. This is a clear co-incidence with the preferred home charging system, which offers Smart Charging options (not explicitly included in the study). See also Figure 74:

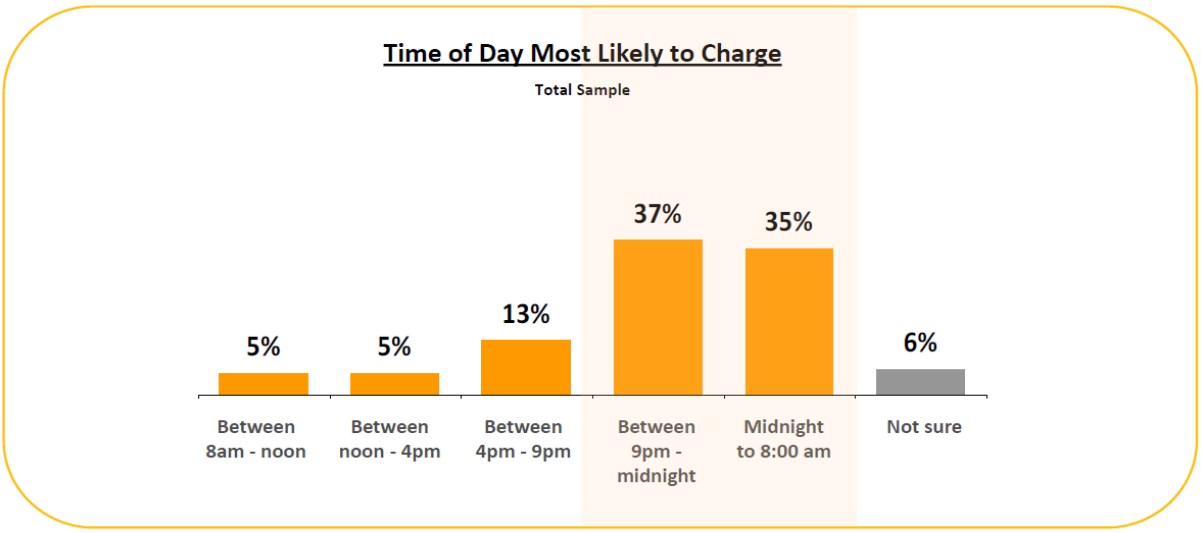


Figure 74. The preferences of residents in car charging times

6.5 Summary

The majority of consumers drive short distances most days and as a consequence do not require the battery to be fully charged before each trip. Most of the urban dwellers can fulfil their daily travel needs without using the public charging infrastructure. New bee EV drivers often have non-realistic expectations from the charging infrastructure as they often expect their car to be charged at a faster rate. EV drivers prefer to charge their EV at home and be free to charge at a time that suits them.

Functional requirements of future charging system from users point of view

New technical possibilities to recharge electric cars might be able to offer solutions to current perceived limitations concerning vehicle driving range. Fast charging moves the recharging process closer to a time span people are used to from conventional liquid fuels. Battery swapping stations are another solution for long-distance travel, but also require a great deal of infrastructure [49] and is not favoured by the majority of the EV drivers. Third future option is the wireless, inductive charging integrated in roads.

Questionnaires have revealed that EV drivers appreciate (highly) automated charging systems. EV drivers for example appreciate that the charger sends a message whenever the battery has reached a prescribed state-of-charge. From this the expectation is that (reliable) highly automated charging systems that guarantee a SOC that is high enough for all planned trips (and preferably also for a few unplanned short trips), and at the same time minimize the costs for charging, will be appreciated by most EV drivers. Next to minimizing costs (which is always appreciated), questionnaires revealed that EV users prefer the use of renewable energy for powering their EVs. Around 50% of the EV users are even willing to pay more when they can charge their EV with renewable energy.

Summary - current EV users expectation based on the survey conclusion, including conclusions not directly linked to this chapter, but discussed in COTEVOS project:

1. Standardization of charging connectors

Standardized plugs and sockets on charging points are the prerequisite for EV users to get unlimited access to the charging service. This is considered as the biggest burden for the spread of EVs in the public.

2. Openness, flexibility and interoperability of charging stations

Access to public charging services is the second precondition. Users expect to get access at any charging station without a heavy administrational burden. Authentication at the stations is a matter of the EVSE operator and it has to be convenient for the customers.

3. Home charging vs. public charging

Home charging is the most preferred charging solution; it is considered as the most simple and most secure way of charging an electric vehicle. Without significant incentives, immediate charging and full driving capacity is preferred comparing to offering services like V2G. In none of the questionnaires a clear statement towards the EV user was (could be?) made on the effect for the EV user when a V2G service would be provided. Therefore an underpinned conclusion on this subject cannot be drawn without further investigation.

4. Availability of public charging infrastructure and parking

A wide (European) and sufficiently dense network of publicly accessible charging stations offer psychological support for the EV users and therefore facilitate the spread of EVs. EV users expect online access to charging station information comprising its availability, reservation options, supported connector type(s), power output and supported payment methods. Mobile applications, web portals and smartphone apps are the usual/expected information channels.

5. Charging payment, reporting, cross-border charging possibilities

Easy to find interoperable chargers supporting various payment options (such as roaming and cash) is what EV users are expecting.

6. Electric vehicle in smart home solution like battery storage

Only few of EV users are interested in using their electric vehicle battery as an energy storage system within their home. Users expect that EVs become part of their home energy systems, where several appliances are managed. Smart Charging is more preferred solution comparing to the EV as battery storage.

7 NEEDS FOR INTEROPERABILITY BETWEEN EVS AND ELECTRICAL POWER SYSTEM – METHODOLOGY

7.1 Interoperability in the Smart Grid context

The intermediate report of the SG-CG interoperability group [73] introduces profiles and discusses how the SGAM model can help reach interoperability in the Smart Grid domain.

From an interoperability point of view, two or more systems are interoperable if they are able to perform cooperatively a specific function by using exchanged information.

As introduction to this section, the next table presents interoperability (IOP) levels according to different models such as the Smart Grid Interoperability Maturity Model (SGIMM), the GWAC Model (GridWise Architecture Council) and the Smart Grid Architecture Model (SGAM). The SGAM will be further described in the next section.

Table 18. IOP level SGIMM mapping from GWAC to SGAM

IOP level according to SGIMM	Addressed GWAC levels	Addressed SGAM levels
Level 5: Plug and Play	Layers 1-8 and CSF requirements implemented	Layers 1-5 and all CSF requirements implemented
Level 4: Certified, minor but planned integration efforts	Layers 1-7 and CSF requirements mostly implemented	Layers 1-5 and CSF requirements without regulatory issues implemented
Level 3: emerging interoperability	Layers 1-5 and CSF requirements implemented	Layers 1-4 and CSF requirements without business procedures implemented
Level 2: initial interoperability	Layers 1-3 and CSF requirements implemented	Layers 1-2 and CSF requirements implemented
Level 1: non interoperable	No awareness of levels	No awareness of levels

7.1.1 Profiles

A profile is a specification that governs information exchanged within a specific business exchange context.

Profiles could be developed to serve the information needs of specific user groups, for instance, European TSOs, German DSOs, etc. Individual companies like utilities or OEMs can also develop their own profiles, as subset of the more generic profiles of a user group.

One of the most important purposes of a profile is to help ensure interoperability between systems. Since Open standards can be vague, the use of profiles can enforce one of the possible interpretations.

The *companion standard* is a profile but referred to a base standard. An example of companion specification is COSEM, which includes a set of specifications defined by the

DLMS protocol, or the IEC 60870-5-104, which describes how the tele-control standard IEC 60870-5 is used over TCP/IP.

The process to create a profile starts with a business problem, identifying the need for standardized interaction among a group of systems/applications to accomplish a business purpose. It is similar to that of developing an open standard and it will follow the process of requirement analysis and use-case development described below.

The profile definition methodology covers only a part of the overall process of defining business interoperability. The following steps should have been already carried out:

- Business problem analysis identifying the functional exchanges that need to be standardized.
- Identification of data requirements of each functional exchange.
- Amendment of the canonical information model in order to express all data requirements.

The profile methodology must produce a precise and testable specification of exchanges among parties. Two things are required:

- Semantic model: specifying the structural elements that capture the information content.
- Syntactic model: it specifies how the semantic model is serialized to be transferred.

7.1.2 Methodology to reach interoperability at Smart Grid Systems

The use of open standards results in interoperability-by-design when applying the correct methodology.

The main steps of the proposed methodology in [73] are described in the following sections.

7.1.2.1 **System design**

The IT Software/System development Life Cycle is proposed. Five stages are identified in it:

- Requirement analysis: description of the system or software behaviour, technical feasibility might be accessed. It can be accomplished through use case description. Interoperability requirements for all layers (e.g. SGAM layers) must be also captured at this stage.
- Design: solution concept and architecture will be considered.
- Implementation: realization of the solution.
- Testing: the implemented solution will be validated. Defects will be reported and corrected.
- Evolution: after the system is launched practical experiences during operation and maintenance will be gathered. New requirements can be collected.

Each stage has its own activities, tasks, inputs, outcomes and deliverables. Depending on the method used (waterfall, V model, agile model, etc.) the process can be slightly different.

7.1.2.2 **Use case identification, creation and selection**

A use case is a description of the possible sequences of interactions between the system under discussion and its external actors, related to a particular goal.

Use cases provide a basis for identifying a system, its functionality, interaction and interfaces. In order to define generic use cases the SG-CG/SP (Smart Grid Coordination Group - Sustainable Processes) adapted the use case template originally defined in IEC PAS 62559:2008-10 for its purpose [7]. Taking this as basis, the TC8 updated the original IEC62559. Although the main purpose of the template is the development of standards, it may also be used for the realization of projects with complex systems, including testing. The main sections included in the use case template are the following:

- **Description of the use case**: scope (limits), objectives (goals), related business case(s), narrative (short and complete description)
- **Diagrams of the use case**: graphical description of interaction between the system under discussion and external actors to its boundary. One example related to the FLISR (Fault Location, Isolation, System Restoration) case is shown below.

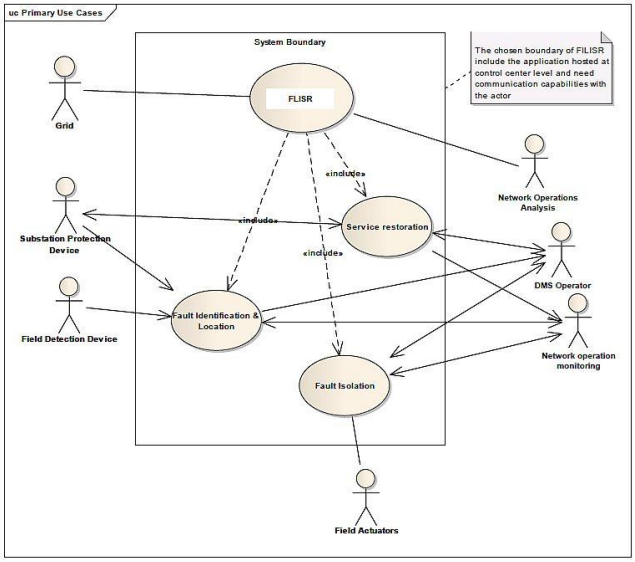


Figure 75. Diagram of use case (FLISR example) [73]

- **Technical details**: actors (anything in the system that communicates) are described.
- **Step by step scenario**: to achieve interoperability, steps description should focus on interactions and information flows between actors. All interactions and information flows must be compliant to the Smart Grid standard (SG-CG/SS).
    - **Scenario conditions** are defined by a name, a primary actor, a triggering event, a pre-condition and a post-condition.
    - **Scenario steps:** For each scenario, all steps involved are described by the event that starts the step (e.g. "fault occurs in the grid"), name and description

of process or activity, service (create, report, get, change, delete, cancel, execute, timer, repeat, etc.), the information producer, information receiver, information exchanged and the Requirements (ID's).

- **Information exchanged:** name of information ID (link to the scenario steps information), description of the information exchanged (using canonical data models is recommended) and requirements to information data (requirements referring to the information and not to the step). Reference to standard data model and specification of information should be done.
- **Requirements (optional):** requirement ID (link to the scenario steps information) and requirement description.

The sections represented by the "step by step scenario", "information exchanged" and "requirements" is the basis for defining the profile for testing purpose.

The next steps after use case definition are the following:

- Review and validation of the use case narrative: check whether the narrative is mapped to SGAM domain.
- Validation of key use case actor and roles: the definition of actors and roles must be in line with standard definitions by the SG-CG.
- Discussion of scenarios or steps to be included in the use cases: standard interfaces and protocols must be used for information exchange between the systems.

The SGAM mapping process can be used to select relevant standards, interfaces and protocols. The first step for mapping, according to the interoperability group [73], will be the identification of domains and zones affected by the use cases. Systems and components should be distributed (component layer). The information layer requires identifying which data or information is to be exchanged between components. The final step is to develop the communication layer.

7.1.2.3 **Testing according to the V Model**

The V model represents a system of software development process proposed in the late 80s. It demonstrates the relationships between each phase of the development life cycle and its associated phase testing:

- **Unit testing**: a unit is the smallest testable part of an application. This test focuses in each component individually. The purpose is to verify the internal logic code.
- **Integration testing**: the separate units will be tested together to expose faults in the interfaces and in the interaction between integrated components. Integration can validate the system interoperability at SGAM information and communication layers.
- **System testing**: the test is performed on a complete, integrated system to check if the product meets the specified requirements for the customer and final users.
- **Acceptance testing**: it means customer agreed tests of the specifically manufactured system installation or its parts. The factory acceptance test (FAT) takes place before installation of the concerned equipment, it includes: check of completeness, verification against contractual requirements, a proof of functionality and a final inspection. The site acceptance test takes place at customers' location.

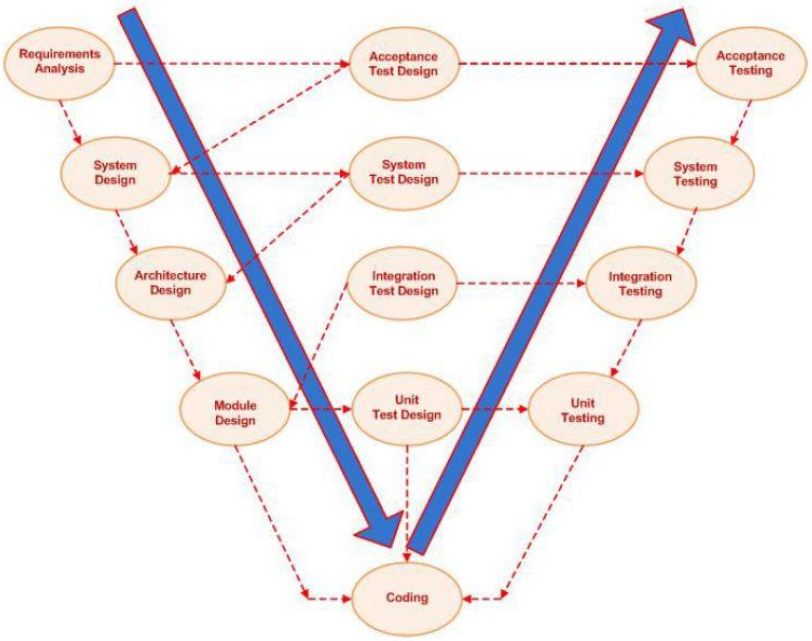


Figure 76. V Model [73]

7.1.2.4 **Testing to achieve interoperability**

The two main types of testing to achieve interoperability are the following:

- **Conformance testing**: determines whether an implementation conforms to the established specifications or profile. The term *conformance* is generally associated with testing programmes that are of a voluntary or market driven nature, while *compliance* is more closely associated with mandatory or regulatory oriented programmes. A typical procedure for conformance testing includes:
    - Identification of candidate "implementations under test" (IUT), protocol implementation considered as an object for testing, which is normally implemented in a System Under Test (SUT).
    - Identification of reference points: interfaces where test systems can be connected.
    - Identification of the Abstract Test Method (ATM): abstract protocol tester and implementation of the abstract test architecture.
    - Development of conformance test specifications.
- **Interoperability testing**: it connects two or more implementations together and determines whether they can successfully interoperate. Devices/systems in should be tested according to the same profile. The systems need to fulfil both syntactic and semantic interoperability. A typical procedure for interoperability testing includes:
    - Identification of candidate Equipment Under Test (EUT), which is a physical implementation of an equipment that interacts with other EUTs.
    - Identification of test scenarios: supporting of the same use cases is required.
    - Definition of test bed architectures: abstract description of logical entities as well as their interfaces and communication links involved in a test.

- Identification of test bed interfaces: interfaces where data is exchanged, control of the various entities in the test bed and control of the test bed control module (test operator).
- Development of interoperability test specifications: developing interoperable function statement (IFS) and test descriptions (TD) from base standards.

A generic methodology for conformance and interoperability testing is described in detail in ETSI EG 202798. Based on it, the next figure illustrates how it is applied to smart grid and the interactions between smart grid base standards and smart grid test specifications.

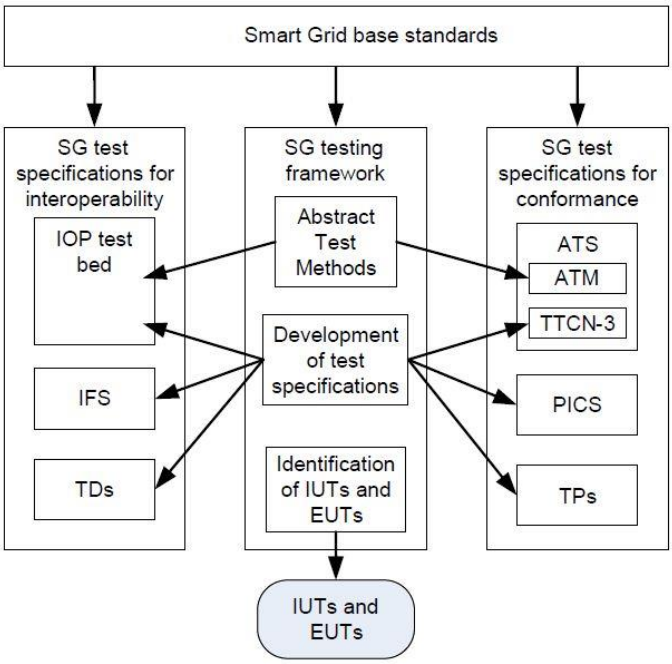


Figure 77. Smart grid testing framework interactions [73]

TTCN-3 is a test specification language. It provides all the constructs and features necessary for black box testing and, as a result of its intrinsic extensibility, it is able to import external data and type specifications directly. Several mappings of external data and type specifications such as ASN.1, IDL and XML are already standardized.

Some key examples for existing standardized testing procedures to reach interoperability are referenced below:

- **IEC 61850 series**: part 5 standardizes the communication between intelligent electronic devices (IED) and defines the related system requirements to provide interoperability between functions residing in the equipment from different suppliers. Since the goal of the standard is interoperability, conformance with the standard means that interoperability is proven. The conformance test specification shall describe what tests have to be applied to the device and the pass criteria will have to be defined. Building interoperable systems requires standardized configuration files to be exchanged between engineering tools, therefore, they will have to fulfil some minimum requirements. Part 10 specifies standard techniques for testing of conformance of client, server and sampled value devices and engineering tools.

- **IEC 61870-5**: part 101 applies to remote control equipment, 103 to protection equipment and 104 presents a combination of the application layer of 101 and the transport functions provided by TCP/IP. Although these companion standards define the most important user functions, it cannot guarantee complete compatibility and interoperability. An additional mutual agreement is normally required between concerned parties regarding the methods to use for defining communication functions.
- **IEC 61400-25:** it defines the information and information exchange using abstract models (independent of a concrete implementation). Part 5 introduces the conformance testing procedure for wind power plants.
- **IEC 62056:** these are the international standard versions of the DLS/COSEM specification.
- **ETSI:** ETSI TS 102237-1 gives general guidance on the specification and execution of interoperability tests for communication systems in next generation networks. It provides a framework within which interoperability test specifications for a wide range of product types can be developed.
- **Common Information Model (CIM):** it is an abstract information model that provides data understanding through the identification of the relationships and associations of the data within a utility enterprise. CIM companion standards such as IEC 62325, IEC61970 and IEC61968, provide extensions and specifications that, when used in conjunction with the CIM models, provide a framework for the exchange of static model, transactional messages and full enterprise integration. CIM interoperability tests are organized by ENTSO-E and UCAIug.
- **ENTSO-E interoperability tests**: they perform at least two types of tests, those to validate a CIM standard as part of the standard development process and test to validate the conformity of available software solutions with an approved standard.
- **UCA user Group CIM interoperability test**: this group evaluates the interoperability of EMS and third-party vendor products through the administration of formal test procedures.
- **ISO/IEC 15118**: FP7 PowerUp R&D project aimed to develop the interface for EV charging, involving a full development cycle of physical/link-layer specification, charging control protocol design, prototyping, conformance testing, field trials and standardization.

A list of the main user groups interested in defining interoperability testing procedures is presented below:

- DLMS UA (Device Message Language Specification User Association).
- UCAIug (UCA International Interest group): UCAIug organization and CIMug (CIM user group).
- ENTSO-E (European Network of Transmission System Operators for Electricity).
- IEC 60870-5 User group mail list.

7.1.3 Process for building interoperable system

Standards are recommended to build an interoperable smart grid system. A utility should define the scope of the smart grid project, developing business and use cases.

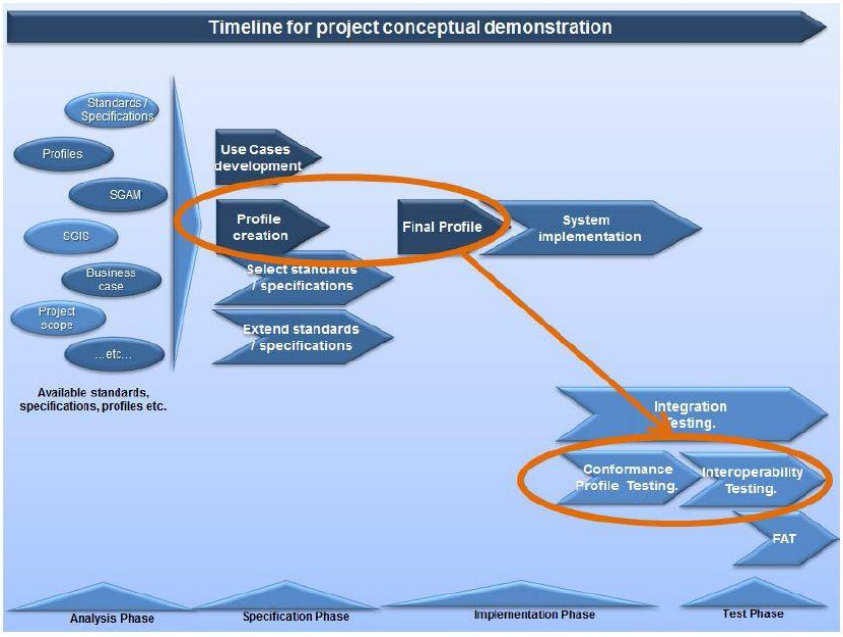


Figure 78. Timeline for project conceptual demonstration [73]

After that, it is necessary to identify available standards and profiles. The IOP tool [73] can be an important help in this process. Based on the use case and the identified standards, a profile can be developed. This should include references to the selected standards and reduce the amount of open options defined in them. If the standards do not provide facilities for all business requirements as defined in the use case, the profile should describe extensions to add additional functionalities while respecting the guidelines.

7.2 Smart Grid Reference Architecture

Based on the content of the M/490 EU Mandate (EC Directorate General for Energy [5] , CEN, CENELEC, and ETSI were requested to develop a framework to enable European Standardization Organizations to perform continuous standard enhancement and development in the field of Smart Grids, while maintaining transverse consistency and promote continuous innovation.

The SGAM Framework was developed in this context and, according to (SG-CG Reference Architecture [9]), it aims at offering a support for the design of smart grids use cases with an architectural approach allowing for a representation of interoperability viewpoints in a technology neutral manner, both for current implementation of the electrical grid and future implementations of the smart grid.

7.2.1 Interoperability in the context of smart grid

Interoperability is seen as a key enabler of EVs as well as of smart grids. The SGAM model addresses inherently interoperability.

Interoperability is defined by [9] as the ability of two or more devices to exchange information and use it to perform a specific function. For the realization of an interoperable function all categories shown in the next figure should be covered by means of standards or specifications.

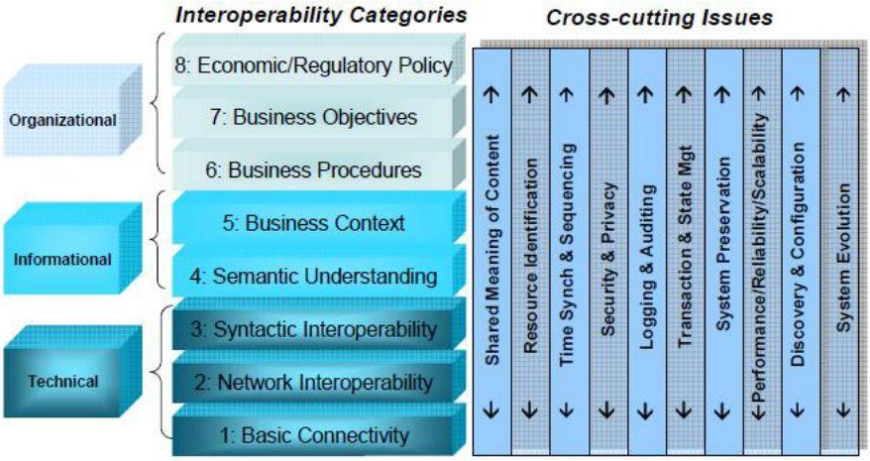


Figure 79. Interoperability categories and cross-cutting issues [9]

Cross-cutting issues are topics that need to be considered and agreed on when achieving interoperability.

7.2.2 SGAM Framework elements

The previously described categories are aggregated into five abstract interoperability layers.

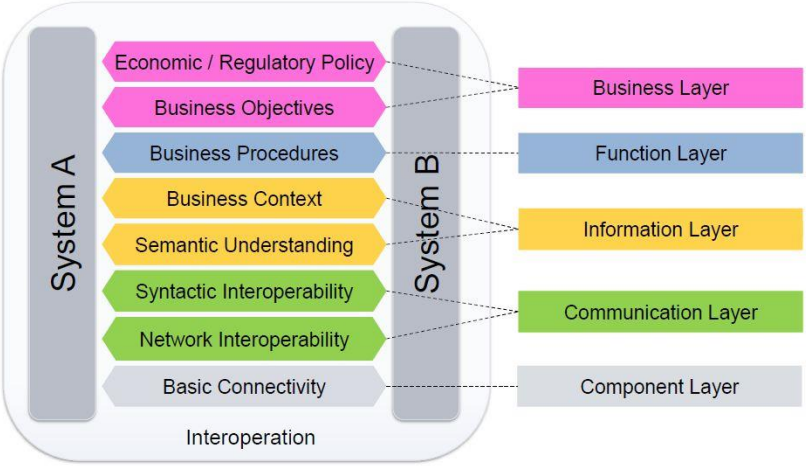


Figure 80. SGAM Interoperability layers [9]

A short layer description is provided below [9]:

- **Business layer**: it represents business view on information exchange related to smart grids. It can be used to map regulatory and economic (market) structures and policies, business models, business portfolios (products & services) of market parties

involved. Also business capabilities and business processes can be represented in this layer.

- **Function layer**: it describes functions and services including their relationship from an architectural point of view. The functions are represented independent from actors and physical implementations in applications, systems and components.
- **Information layer**: it describes the information that is being used and exchanged between functions, services and components. It contains information data models and the underlying canonical data models. These information objects represent the common semantics for functions and services in order to allow interoperable information exchange via communication means.
- **Communication layer**: it describes protocols and mechanisms for the interoperable exchange of information between components.
- **Component layer**: it is focused on the physical distribution of all participating components in the smart grid context. This includes system actors, applications, equipment, network infrastructure (communication connections, routers, switches, servers…)

In addition to layers, the SGAM framework is also represented by domains and zones, which define the smart grid plane:

- **Domains**: five domains are considered, representing subsystems of the electricity network infrastructure: bulk generation, transmission, distribution, DER and customer premises.
- **Zones**: they represent the hierarchical levels of power system management:
    - **Process:** physical, chemical or spatial transformations of energy and the physical equipment directly involved (generators, transformers, circuit breakers, lines, etc.).
    - **Field:** equipment to protect, control and monitor the processes of the power system (protection relays, data acquisition and processing devices, etc.).
    - **Station:** aggregation for field level (substation automation, local SCADA systems).
    - **Operation:** power system control systems (DMS, EMS, VPP and Microgrid management systems, EV fleet charging management systems).
    - **Enterprise:** commercial and organizational processes, services and infrastructures for enterprises (asset management, logistics, customer relation, billing).
    - **Market:** market operations management (energy trading, retail market).

An actor (a service provider, for example) could be located at any segment of the smart grid plane according to the role he has in a specific case.

7.2.3 SGAM framework

Merging all three dimensions, layers, domains and zones, a three dimensional model is obtained and this constitutes the SGAM framework.

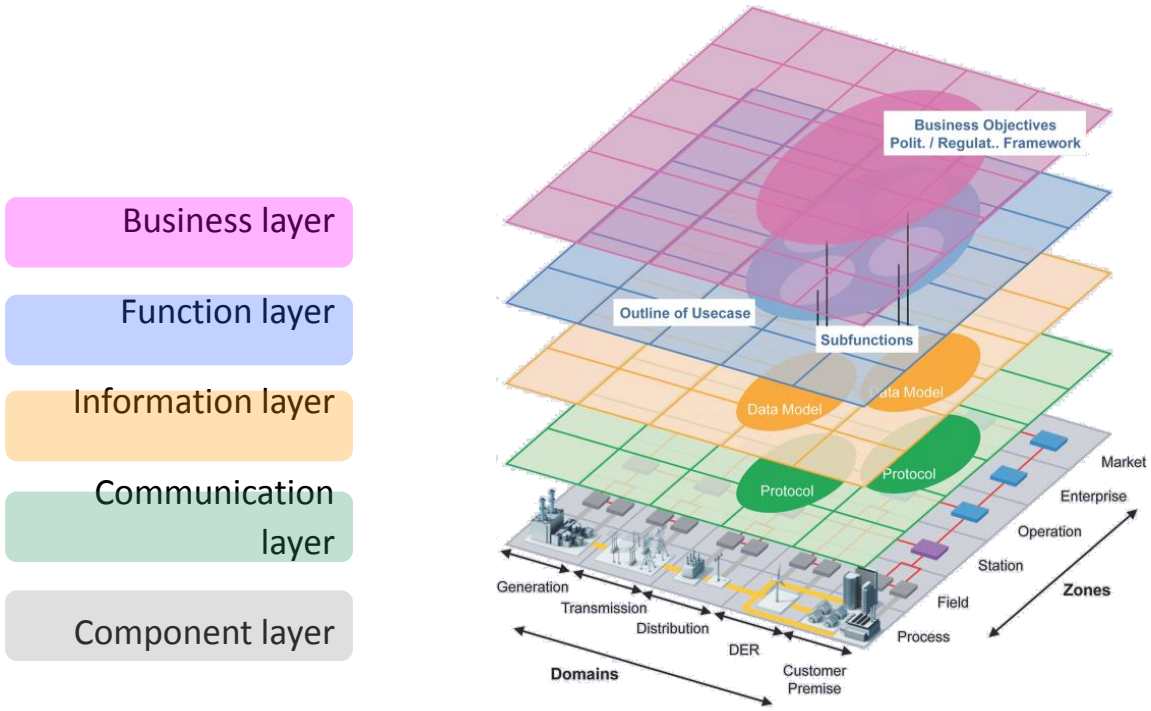


Figure 81. SGAM Framework layers [9]

The above described cross-cutting issues have an impact on all the layers of the model.

Since electrical vehicles (EV) will be part of smart grids and they should be integrated at all levels in their framework, this model will be used to analyse interoperability aspects related to information exchange, communications and protocols among players and systems in the EV service provision environment. In the next sections, the above mentioned SGAM layers will be defined more in detail according to the EV case and the work already developed at EU standardization level will be used as basic reference.

7.2.4 SGAM methodology

The main objective of the SGAM methodology is to identify gaps in standardisation. This is done by mapping use cases, functions or services, through involved entities, into the 3D model. When a layer remains open, it implies that there is no specification or component available to support the use case, function or service.

The consistency of an interoperable interaction can be represented by a consistent chain of entities, interfaces and connections in the SGAM layer.

The process of mapping use cases to the SGAM framework can be accomplished through the following steps (constraints may have an impact on their sequence):

Use case analysis: it must be checked that the information on the use case is complete before starting with the mapping [7] provides a suitable use case template):

- Name, scope and objective
- Use case diagram

- Actor names, types
- Preconditions, assumptions, post conditions
- Use case steps
- Information which is exchanged among actors
- Functional and non-functional requirements

Component layer: its content is derived from the use case information on actors, since these can be of type devices, applications, persons and organizations.

Business layer: it must include business processes, services and organizations. Also business objectives, economic and regulatory constraints.

Function layer: functions stem from the use case by extracting its functionality. Typical use case consists of several sub use cases with specific relationships.

Information layer: it describes the information that is being used and exchanged between functions, services and components. The information objects are defined in form of use case steps and sequence diagrams.

Communication layer: it is used to describe protocols and mechanisms for the interoperable exchange of information between the use case actors.

7.3 SG-CG use case mapping on SGAM

The Smart Grid Coordination Group carried out some smart grid use case mapping work into the SGAM, which could be used as framework and reference for EV use case mapping, if we consider the EV as a device part of smart grids. This work was intended to build a first list of standards to support smart grid systems in Europe [8] as requested though the M/490 mandate.

7.3.1 List of systems

The following table lists a set of smart grids systems identified in [8]. A column has been added to address the possible link with e-mobility.

Table 19. List of systems and link with e-mobility

Domain or function	System	Link with e-mobility
Generation	Generation management system	no direct connection
Transmission and management system	Substation automation system	no direct connection
	Wide Area Measurement System (WAMS)	no direct connection
	EMS SCADA System	no direct connection
	Flexible AC Transmission Systems (FACTS)	no direct connection
Distribution management systems	Substation automation system	no direct connection
	Feeder automation/smart reclosers system	no direct connection
	Distributed power quality control system	related to EVs if they offer V2G

	DMS SCADA system and GIS system	no direct connection
	FACTS system	no direct connection
DER management systems	DER operation system	when EV charge can be controlled
	DER EMS and VPP system	when EV charge can be controlled
Smart metering systems	AMI system	related to EVSEs and residential EV charge
	Metering back office system	related to EVSEs and residential EV charge
Demand and generation flexibility systems	Aggregated prosumers management systems	when EV charge is controlled
Marketplace system	Marketplace system	EV services market place
	Trading system	Trading systems for EV charge
E-mobility (connection to grid)	E-mobility systems	direct connection
Administration systems	Asset and maintenance mgmt. system	related to EVSE operators
	communication network management system	related to all actors with communication systems
	Clock reference system	required for real time operation when no external clock is used
	Authentication authorization accounting system	related to the access to EVSE for charging
	Device remote configuration system	related to EVSE operators or OEMs (though they have own systems)
	Weather observation and forecast system	related to services offer for EV users

If these systems were positioned in the SGAM grid plane the following figure would be obtained.

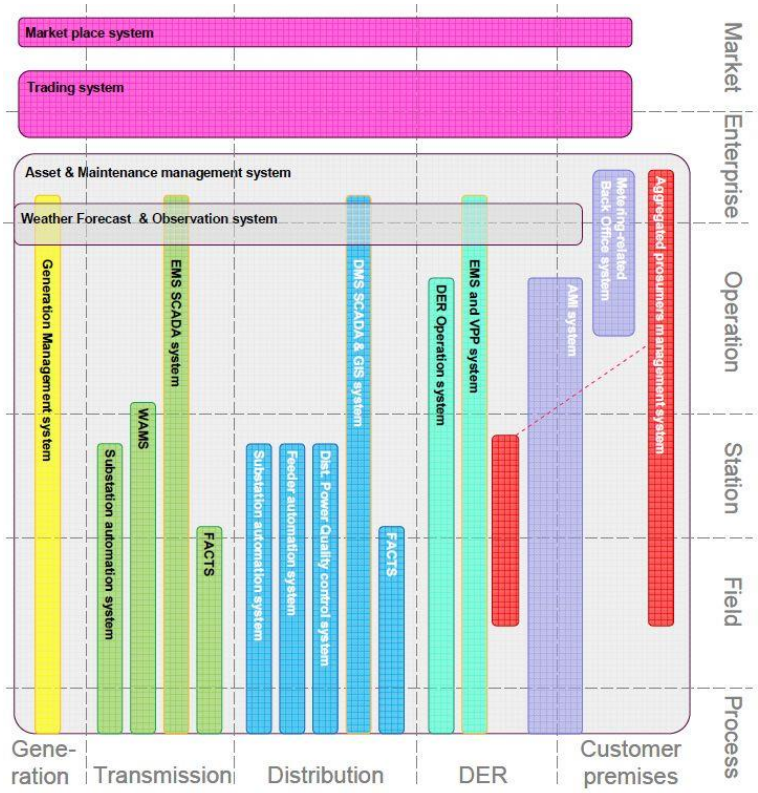


Figure 82. Mapping of smart grid systems to the SGAM model [8]

7.3.2 Smart grid generic use cases

The next table shows an extract of the smart grid high level use cases in [8], including only those that could be relevant for e-mobility. Here also an additional column has been added for e-mobility link identification.

Table 20. Summary list of Smart Grid Generic use cases

Nº	Use Case Cluster	High level use cases	Link with e-mobility
1.	(AMI) Billing	Obtain scheduled meter reading	Energy suppliers, EVSE operators, EVSP tasks
		Set billing parameters	
		Add credit	
		Execute supply control	
2.	Billing	Obtain meter reading data	Residential charge and EVSE operators
		Support prepayment functionality	
		Manage tariff settings on the metering system	
		consumer move-in/move-out	
		supplier change	
3.	Blackout management	Black-out prevention through WAMS	EV provision of ancillary services through an
		Provision of black start facilities for grid restoration	

		Restore power after blackout	aggregator
		Shedding loads based on emergency signals	
		Under frequency shedding	
4.	(AMI) Collect events and status confirmation	Manage supply quality	Energy suppliers, EVSE operators, EVSP tasks
5.	(AMI) Configure events, statuses and actions	Configure meter events and actions	Energy suppliers, EVSE operators, EVSP tasks
		Manage events	
		Retrieve AMI component information	
		Check device availability	
6.	(AMI) Customer information provision	Provide information to consumer	Energy suppliers, EVSE operators, EVSP tasks
7.	Demand and generation flexibility	Generation forecast	EVs can provide demand (and generation if V2G is available) flexibility to the network
		Load forecast	
		Load forecast of a bunch of prosumers in a DR programme (from remote)	
		Managing energy consumption or generation of DERs via local DER energy management system bundled in a DR programme	
		Managing energy consumption or generation of DERs and EVSE via local DER energy management system to increase local self-consumption	
		Participating to the electricity market	
		Receiving metrological or price information for further action by consumer or CEM	
		Registration/deregistration of customers in DR programme	
		Registration/deregistration of DER in DR programme	
8.	(AMI) Energy market events	Manage consumer moving in	Energy suppliers, EVSE operators, EVSP tasks
		Manage consumer gained	
		Manage customer lost	
		Manage customer moving out	
9.	Exchange of metered data	Measure collected data	Energy suppliers, EVSE operators, EVSP tasks
		Measure for imbalance settlement	
		Measure for labelling	
		Measure for reconciliation	
		Measure, determine meter read	
		Measure, determine meter read for switch	
10.	Generation operation scheduling	Ancillary services and reserve products control	Only if EV could offer V2G and market penetration would allow high capacities (reduced impact in the short term)
		Day-ahead fleet scheduling	
		Day-ahead hydro plant valley scheduling	
		Fuel and other resources allocation, cogeneration and other by-products production	

		Intra-day fleet scheduling	
		Plant scheduling	
11.	(AMI) installation and configuration	AMI component discovery & communication setup	Energy suppliers, EVSE operators, EVSP tasks
		Clock synchronization	
		Configure AMI device	
		Security configuration management	
12.	Maintaining grid assets	Archive maintenance information	DSO or EVSE operator tasks
		Monitoring assets conditions	
		Optimize field crew operation	
		Supporting periodic maintenance (and planning)	
13.	Manage commercial relationship for electricity supply	Further from ESMIG	EVSP and retailer tasks
		Further suggestions to market	
		Invoicing customers	
		Registration/deregistration of customers	
14.	Monitor AMI event	Install, configure and maintain the metering system	Energy suppliers, EVSE operators, EVSP tasks
		Manage power quality data	
		Manage outage data	
		Manage the network using metering system data	
		Manage interference to metering system	
		Enable and disable the metering system	
		Display messages	
		Facilitate DER for network operation	
		Facilitate demand response actions	
		Interact with devices at the premises	
		Manage efficiency measures at the premise using metering system data	
		Demand side management	
15.	Operate DER	Aggregate DER as commercial VPP	EV as DER. Retailer, EVSP, aggregator, EVSP tasks
		Aggregate DER as technical VPP	
		DER performance management	
		DER process management	
		DER process management with reduced power output	
		DER remote control (dispatch)	
		Registration/deregistration of DER in VPP	
		Store energy from the grid	
16.	System and security management	User management	DSO, EVSE operator tasks
		Role management	
		Rights/privileges management	
		Key management	

		Events management	
		Configure newly discovered device automatically	
		Discover new component in the system	
		Distributing and synchronizing clocks	
17.	Trading front office operation	Bid into energy markets	EVSP, aggregator tasks
		Compute optimized assets schedules to match commercial contracts	
		Send assets schedules to operation systems	
		Bid into ancillary services markets	
		Purchase transmission capacity rights	
		Nominate schedules to system operator	
		Send market schedules to operation systems	
		Publish market results	
18.	Trading back office operation	Perform M&V	EVSP, aggregator tasks
		Perform shadow settlements	
19.	Weather condition forecasting & observation	Wind forecasting	EV user services providers
		Solar forecasting	
		Temperature forecasting	
		Providing weather observations	
		Situational alerting	

7.3.3 List of components

Smart grid components are specified in [8], based on IEC SMB SG3 work. In the next figure, components are mapped into the SGAM grid plane and the following table lists and describes those that may have a link with e-mobility.

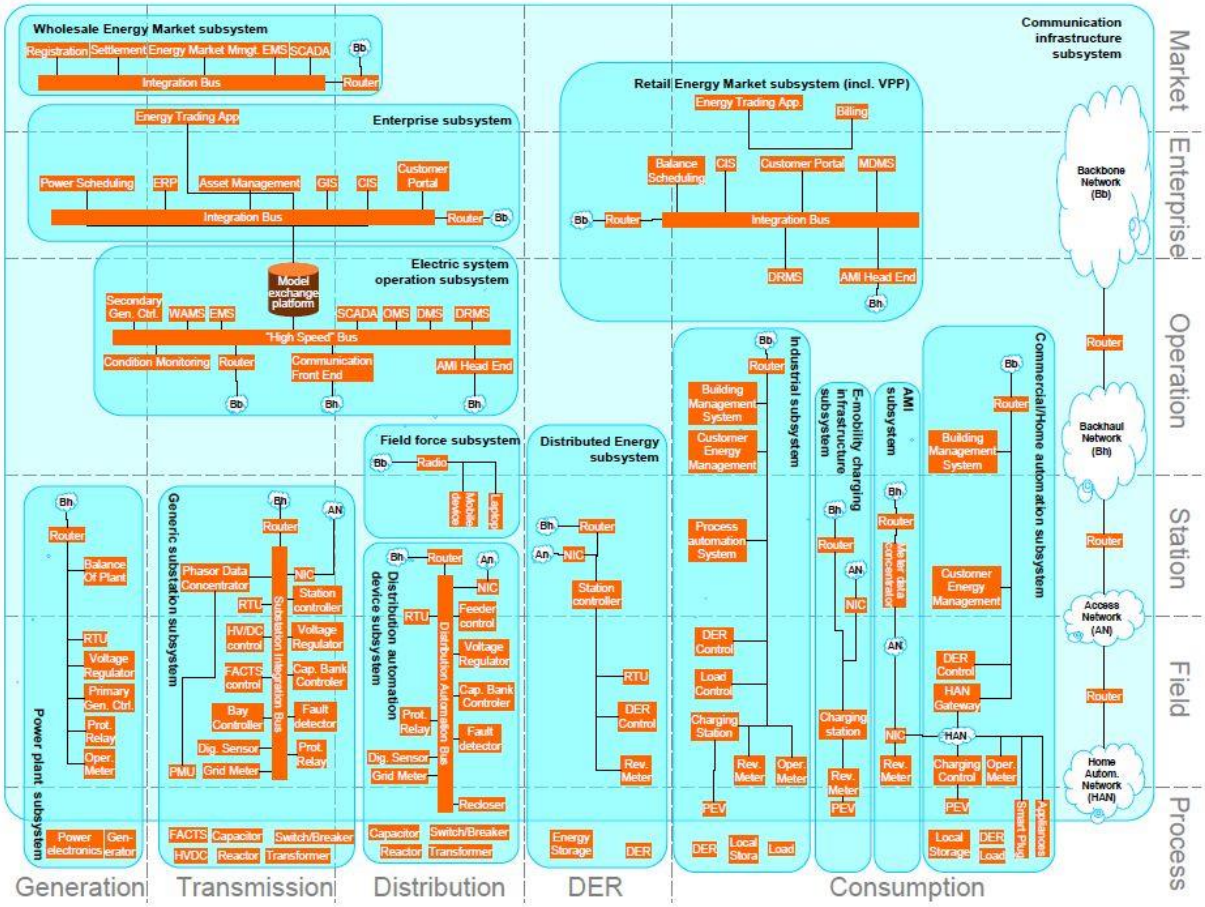


Figure 83. Component mapping on Smart Grid plane [8]

Table 21. Smart grid component list

Component	Description	Link with e-mobility
AMI Head end	Back-end for metering communications. Controls and monitors the communication to meter devices	Meter operator, DSO and EVSE operator may use it
Appliances	Appliances within buildings providing an interface to influence their consumption behaviour	The EV could be considered an appliance
Asset management	Application optimizing the utilization of assets, regarding loading, maintenance and lifetime	DSO and EVSE operators could require it
Billing	Application which creates the energy bill information based on received metering information	EVSE, retailers, EVSE operators could use it
Building Management System	A system consisting of several decentralized controllers and a centralized management system to monitor and control facilities within a building.	It might control EV load in building environments
Charging control	Controls the charging of one car at a residential customer side according to set points received from the customer‘s energy management	directly related
Charging station	Single or multiple power outlets specially designed to charge the battery of cars. Typically including also facilities to meter the energy consumption and to authenticate the owner of the car for settlement reasons	Directly related

Component	Description	Link with e-mobility
Communication Front End	Application or system providing communication with the substations to monitor and control the grid	General scope system that could be used for e-mobility
Customer Energy Management System	EMS for energy customers to optimize the use of energy according to supply contracts or other economic targets	It might control EV load in residential, industrial and commercial environment
Customer Information System (CIS)	System or application which maintains all information for energy customers. For example, call centre software to provide customer services like hot-line	EVSP, retailers, aggregators might require it
Customer Portal	Web-server application which allows utility customers to register and login to retrieve information about their tariffs, consumption and other information	EVSP, retailers, aggregators might require it
Demand Response Management System (DRMS)	System or application which maintains the control of many load devices to curtail their energy consumption in response to energy shortages or high energy prices.	DSO, EVSP, aggregators, EVSE operators might use it
DER control	It allows the adjustment of its active or reactive power output according to a received set point	Only if V2G was deployed
Distributed Energy Resource (DER)	A small energy generation unit connected to the distribution grid. Loads able to follow external set points are often considered DER	EVs can be considered as DER if controllable
Distribution Management System (DMS)	Application server of a DMS which hosts applications to monitor and control a distribution grid from a centralized location, typically the control centre. A DMS typically has interfaces to other systems, like an GIS or an OMS	DSOs tool. It could interact with EV or EVSE management applications and systems
Energy Management Gateway (functional)	Gateway used to interface the private area with remote service provider and smart metering system	Used to control EV load in residential, industrial and commercial environment
Energy Management System (EMS) (application server)	Application server of an EMS hosting applications to monitor and control a transmission grid and the output of the connected power plants from a centralized location. An EMS may have interfaces to other EMS.	It could also control EVSEs
Energy Market Management	Application of system which manages all transactions and workflows necessary to implement an energy market	For market place operators
Energy Storage	An electrical energy storage installed within the distribution grid or DER site and operated either by a utility or energy producer	The EV could be used as storage for the grid in the future
Energy trading application	Application/s used to trade energy in corresponding markets. They support the dispatcher in the decision to buy, sell or to self-produce energy and provide facilities to exchange the information with energy market IT systems	EVSP, aggregator may require it
Enterprise Resource Planning (ERP)	These systems integrate internal and external management information in an organization, embracing finance/accounting, manufacturing, sales and service, customer relationship management, etc.	It could be used by any company
Front End Processor (FEP)	System in charge of interfacing widely spread remote sub/systems or components usually communicating over WAN, to a central database	It might be used by EVSE operators, aggregators
Geographic Information System (GIS) (application server)	Server hosting an application designed to capture, store, manipulate, analyse, manage, and present all types of geographical data. GIS is the merging of cartography, statistical analysis, and database technology.	It might be used by DSO, EVSE operator, fleet operator

Component	Description	Link with e-mobility
HAN gateway	A specialized gateway device or application which establishes the communication between external systems and the Home Automation Network (HAN) devices	It might be used for EV control at residential level
Head End System (HES)	Central data system exchanging data via the AMI of various meters in its service area	To handle several meters: DSOs, EVSE op.
Load	Energy consuming devices at customer site which might become subject for energy management	the EV is a load
Load controller	It controls the energy consumption of a load according to a received set point without jeopardizing its process	For EV load control
Local network access point (LNAP) (functional)	Specialized Network Interface controller between the Local Network (private area) and the AMI system	Used for AMI
Local storage	Electric energy storage installed behind the meter point, operated by the energy consumer/producer	An EV could perform this role
Meter data concentrator	Device or application typically in a substation which contacts smart meters to collect the metered information and send it concentrated to an AMI head end	It could be used by a EVSE operator
Meter data management system (MDMS)	System or application which maintains all information needed to calculate the energy bill for a customer from the meter data retrieved from AMI head end(s). This information is typically forwarded to consumer relationship and billing systems	It could be used by an EVSP, aggregator, retailer
MID meter	Revenue Meter compliant with the European MID directive (2004/22/CE) currently under revision	EV charge will be metered in most cases
Model exchange platform	Data warehouse system or application enabling the interchange of information described by the operation data model	
Neighbourhood network access point (NNAP) (functional)	Specialized Network Interface Controller between the Neighbourhood Network and Wide Area Network (WAN) connecting the Head End Systems	Used for AMI
Outage management system (OMS)	System or application to help network operators handle outages and optimizing the reparation depending on number of customer minutes lost, number of affected customers, capability of the network, etc.	Indirectly related if EVs are used to face outages
Plug-in Electric Vehicles (PEV)	A vehicle with an electric drive and a battery which can be charged at a charging station.	Directly related
Power electronics	Generation which uses power electronics to inject electrical energy into the grid (typically DER)	Related to off- and on-board EV chargers
Radio	Wireless communication	It might be involved in e-mobility communications
Registration	Application in an energy market system which handles user registration and monitors its transactions	It could be used for a market place, clearing house
Remote Terminal Unit (RTU)	Microprocessor-controlled electronic device that interfaces objects to a distributed control system or SCADA by transmitting telemetry data and by using messages from the supervisory	Only could be related if it were used in a e-mobility related infrastructure
Revenue meter	Device which measures the energy consumption within predefined cycles for billing purposes	EV charge will be metered in most cases

Component	Description	Link with e-mobility
Router	TCP/IP communication device typically interconnecting an internal network with the public network infrastructure	General for communications
Settlement	Application in an energy market system which maintains the commercial information from energy transactions	For market place and clearing house operators
Smart plug	Load switch which can be controlled by the customer energy management via the home automation network	It might be a way to control EV charge in mode 1 and 2
Supervisory Control and Data Acquisition (SCADA)	It provides the basic functionality for implementing EMS or DMS. It provides the communication with the substations to monitor and control the grid	It could be used by a DSO, aggregator, EVSE operator

7.3.4 Use case mapping

The SG-CG considered several smart grids related use cases and tried to identify standardization gaps through the SGAM methodology. Even if most of these use cases are not totally related to e-mobility, EVs and EVSEs are electrical devices that can be considered as any other asset connected to the system and, therefore, they can be managed in different ways depending on the regulatory and business aspects of system operators and other stakeholders.

The first set of standards report [8] is a reference for smart grid related standardization and it is used in this first stage of the project to present a global perspective of communication and information protocols that may affect the control of EVs and/or EVSEs, not only from the point of view of dedicated standards but also considering them part of the future distribution grids.

7.3.4.1 **Smart grid use cases affecting the profitability of the e-mobility**

Use cases related to distribution grids and load/generation management were selected in this chapter, in order to highlight the load flexibility that EVs may offer to the system, considering both their energy consumption and their storage/generation capabilities. Some of the identified standards were and are in development stage. More detailed information can be found on the referenced document.

The following smart grids systems, which take part of several use cases presented in Table 20, may profit about e-mobility services:

- **Distribution management systems**:
  - **Substation automation**: It refers to the system and all the elements needed to perform automated operation of a substation and of connected assets, form grid lines to loads. The main standards considered are shown in the following table. Network types are further described below in chapter 7.3.4.3.

Table 22. Substation automation communication and information

Zone	Communication	Information	Network type

Zone	Communication	Information	Network type
Process	IEC 61850-9-2	IEC 61850-7-4	Intra-substation
Process - Field	IEC 61850-8-1 IEC 61850-9-2	IEC 61850-7-4	Intra-substation
Field	IEC 61850-8-1 IEC 61850-90-5	IEC 61850-7-4	Intra-substation Inter-substation
Field-station-operation	IEC 60870-5-101 IEC 60870-5-104 IEC 61850-90-2	IEC 61850-7-4 IEC 61850-80-1	Inter-substation WAN
Operation		IEC 61968 IEC 61970	

- **DMS SCADA and GIS system**: DMS SCADA refers to the real-time information system and all the elements needed to support all the relevant operation activities and functions used in distribution automation at dispatch centres and control rooms. It provides the following main functions: real time monitoring and control (SCADA), advanced network applications including network modelling, outage management and work management. GIS refers to the information system and all the elements needed to capture, store, manipulate, analyse, manage and present all types of geographical data and information.

Table 23. DMS SCADA and GIS system communication and information

Zone	Communication	Information	Network type
Process - Field	IEC 61850 IEC 60870-5-103		Intra-substation
Station	IEC 61850	IEC 61850-7-4	Intra-substation
Station-Operation	IEC 60870-5-101 IEC 60870-5-104 IEC 61850-90-2	IEC 61850-80-1 IEC 61850-90-2	WAN
Operation-Enterprise	IEC 61968-100 IEC 60870-6	IEC 61968 IEC 61970	Enterprise Intra control/data centre

- **DER operation system**: it is responsible for the operation of DER assets. It performs supervision and maintenance of the components and provides information to the operators and field crew personnel and interacts with the DER EMS/VPP and the DER asset and maintenance management systems. In cases where DER assets are owned or operated by the DSO, the DER operation systems might be part of the DSOs DMS SCADA system.

Table 24. DER operation system communication and information

Zone	Communication	Information	Network type
Field	IEC 61158 IEC 61784-1	IEC 61131 IEC 61499	Industrial fieldbus area
Field-Station	IEC 61850-8-1	IEC 61850-7-4 IEC 61400-25-2 IEC 61850-7-410 IEC 61850-7-420 IEC 61850-90-7 IEC 61850-90-9	Intra-substation

Zone	Communication	Information	Network type
Station-Operation	IEC 60870-5-101 IEC 60870-5-104 IEC 61850-90-2 IEC 61850-8-2 IEC 61400-25-4	IEC 61850-7-4 IEC 61400-25-3 IEC 61850-7-410 IEC 61850-7-420 IEC 61850-90-7 IEC 61850-90-9 IEC 61850-90-10 IEC 61850-90-15 IEC 61850-90-11	Field area WAN
Operation-Enterprise	IEC 61968-100	IEC 61968 IEC 61970	Enterprise Intra control/data centre

- **DER EMS and VPP systems**: they refer to the operation and enterprise management system and all the elements needed to control the generation and storage process of a single DER entity or a set of DER combined to a VPP. The DER EMS/VPP can act as a technical VPP, interacting directly with the DSO, or a commercial VPP, interacting with the energy market.

Table 25. DER EMS and VPP system communication and information

Zone	Communication	Information	Network type
Field	IEC 61158 IEC 61784-1	IEC 61131 IEC 61499	Industrial fieldbus area
Field-Station	IEC 61850-8-1	IEC 61850-7-4 IEC 61400-25 IEC 61850-7-410 IEC 61850-7-420 IEC 61850-90-7 IEC 61850-90-9	Intra-substation
Station-Operation	IEC 60870-5-101 IEC 60870-5-104 IEC 61850-90-2 IEC 61850-8-2 IEC 61400-25-4	IEC 61850-7-4 IEC 61400-25 IEC 61850-7-410 IEC 61850-7-420 IEC 61850-90-7 IEC 61850-90-9 IEC 61850-90-10 IEC 61850-90-15	Field area WAN
Operation (interaction with the DMS system)	IEC 61968-100	IEC 61968 IEC 61970	Enterprise network
Operation-Enterprise	IEC 61968-100	IEC 61968 IEC 61970	Intra control/data centre Enterprise
Enterprise-Market	IEC 61968-100	IEC 62325 OASIS EMIX EnergyInterop	Balancing

- **Smart metering systems (AMI system and back office systems):** it refers to the whole advanced metering infrastructure including the smart meter, the internal display device, the in-home gateway (Local Network Access Point, LNAP), the meter data concentrator (Neighbourhood Network Access Point, NNAP) and the Head-end system (HES). It is limited to revenue metering at customer premises. It provides the following services: automated meter reading and billing, network monitoring and control and demand response / demand side management in connection with demand and generation flexibility systems. The

market model chosen in [8] considers that the Energy Management Gateway (EMG) and the meter (MID meter) are not owned/operated by the electricity service supplier, but this might vary depending on the country. The EN TR 50572 [70] sets out the SM-CG reference architecture, communications interfaces and associated standards used in the AMI. In the next table few options are shown.

Table 26. AMI system communication and information

Zone	Communication & Information	Network type
Process (meter)-Field (LNAP)	IEC 62056 (DLMS/COSEM) M-Bus	LAN
Field (EMG)-Field (LNAP)	IEC 62056 (DLMS/COSEM) Meters & More HBES M-Bus	LAN
Field (LNAP)-Station (NNAP)	IEC 62056 (DLMS/COSEM) Meters & More M-Bus	Neighbourhood network
Field (LNAP)-Operation (HES)	PSTN	Subscriber access
Station (NNAP)-Operation (HES)	IEC 62056 (DLMS/COSEM) TISPAN NGN Mobile phone networks: 3G, GSM...	Field Area
Operation(HES)-Enterprise(back office)	IEC 61968-100 IEC 61968	Intra data/control centre WAN
Enterprise(back office)	IEC 61968-100 IEC 61968-9 COSEM	Intra data/control centre Enterprise

- **Demand and generation flexibility systems (aggregated prosumers management systems):** flexibility can be implemented directly by an authorised actor via a suitable WAN communication management system, linking the enterprise's user management system (EDM) with the energy management gateway at customer premises (including EVs) and the CEM, smart appliances or generation equipment. Alternatively, the AMI can be used as the channel to the home/building, with communications routed via utility's HES, NNAP and LNAP (check Table 27). The energy management gateway and the CEM might be also integrated.

Table 27. Aggregated prosumers management system communication and information

Zone	Communication & Information	Network type
Field (LNAP)-Operation (HES)	IEC 62746 (Open ADR)	Subscriber access
Operation(HES)-Enterprise(EDM)	IEC 61968-100 IEC 61968	Intra data/control centre
Enterprise (EDM - Metering back office)	IEC 61968-100 IEC 61968	WAN Enterprise

- **Marketplace systems (marketplace and trading)**: marketplace refers to a system where buyers and sellers of a commodity meet to purchase or sell a product in a transparent and open manner according to some rules. Some

marketplace types are, for example, wholesale electricity, marketplaces for products needed for grid reliability (transmission capacity, ancillary services, balancing energy) operated by transmission systems, forward capacity markets and retail market places (for instance to sell and purchase flexibility). Trading systems are used by market participants to interact with other market participants or with central marketplaces. Some of their functions are the front-office (contract management, deal capture, bidding, risk management) and back-office (settlements).

Table 28. Marketplace systems communication and information

Zone	Communication	Information	Network type
Operation-Enterprise (trading system)	IEC 61970 IEC 60870-5 IEC 60870-6	ebIX and EFET are working on this	Intra data/control centre Enterprise
Enterprise-Market	ENTSO-E ECAN ESS ERRP ESP IEC 62325-451 IEC 62325-450	IEC 62325-301 IEC 62325-351 ENTSO-E role model IEC 61970-301 IEC 61968-11 IEC 62351	Trans-regional/national Interchange Balancing

- **Administration systems:**
  - **Asset maintenance and management: i**t is referred to the information system and all the elements needed to support the team in charge of managing the system assets along its total lifecycle. EVSEs could be perhaps considered as a network asset.

Table 29. Asset maintenance and management systems communication and information

Zone	Communication	Information	Network type
Field-Station	IEC 61850-8-1 IEC 61850-8-2 IEC 61850-90-2 IEC 60870-5-101 IEC 61870-5-104	IEC 61850-90-3	Intra-substation Low-end intra-substation Field area Industrial fieldbus area WAN
Station-Operation-Enterprise	IEC 61968-100	IEC 61968 IEC 61970 IEC 61968-4 IEC 61968-6	Enterprise Intra control/data centre

  - **Communication network management system:** they are concerned with the management of the communication networks used for smart grid communication, for example, WAN, LAN and NAN. When communicating devices can be managed remotely they are usually called managed devices and the network having this property is called managed network. A network management system executes applications that monitor and control managed devices. It is very difficult to map a communication network management system into a SGAM, since these systems have their own architectural structure. Various network management standards

exist but in [8] the focus is set on management of the IP layer. A managed device is a network node that implements a SNMP (Simple Network Management Protocol) interface that allows unidirectional or bi-directional access to node specific information. An agent is a network management software module that resides on a managed device. It has local knowledge of management information and translates that information to or from a SNMP. The SNMP uses the ASN.1 (Abstract Syntax Notation One) to represent its manageable objects (they are independent from the used machine).

Table 30. Communication network management systems communication and information

Zone	Communication	Information	Network type
Process-Field-Station	IEC 61850 IEC 62351-7		All
All	SNMP	SNMP ASN.1 IEC/TS 62351-7	All

- **Clock reference system:** Many smart grid systems need a unified global time and synchronized clocks, distributed among all components, to support time critical use cases. An alternative to this is to rely on the absolute reference time provided, for example, by a GPS system.

Table 31. Clock reference systems communication and information

Zone	Communication	Information	Network type
Process-Field-Station	PTP IRIG-B	UTC (ISO 8601)	Inter-substation Intra-substation
All	IEC 60870-5-5 SNTP/NTP	TAI	All

- **Authentication, Authorization and Accounting (AAA)**: it refers to information systems used to grant access to a device or service buy controlling what a given user or system can access and how. The AAA is built mainly in three systems: supplicant, authenticator and authentication server. Supporting standards exist, for example, the EAP (Enhanced Authentication Protocol), which can be mapped to protocols like IEEE 802.1x. or RADIUS.

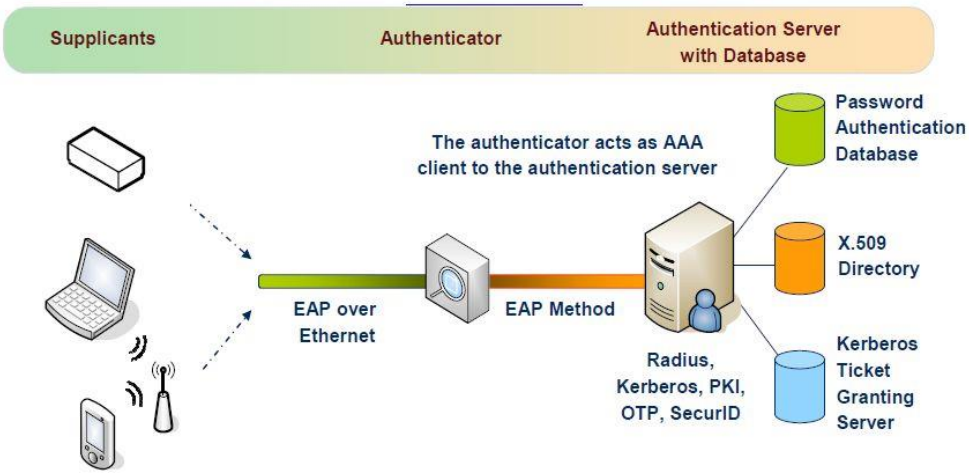


Figure 84. Authentication, Authorization, Accounting (AAA) - EAP overview [8]

Another option for the communication between the authenticator and the authentication server is TACACS+ (Terminal Access Controller Access-Control System), which unlike RADIUS uses TCP for communication. The approach for accessing remotely a substation often relies on the application of a VPN connection based on IPsec and the use of a dedicated VPN gateway. In the future, the security may be enhanced by using IEC 62351, especially for connections using IEC 61850 or IEC 60870-5-104. This approach does not require a specific VPN connection although this will be still useful for applications such as Voice over IP. Access control based on authentication of persons or components in these use cases can be provided by different means: username/password, X.509 certificates and corresponding private keys and security tokens (one-time password generators, smart cards, RFID token, etc.). Authentication means can also be directly derived from the EAP method. Depending on the case, these means may be applied just locally. This may include the local management of accessing peers (persons or devices), roles and associated rights. Moreover, these means may be sued as part of the communication protocols on different OSI layers or the access may be delegated from the station level to the operation level.

Table 32. AAA systems communication and information

Zone	Communication	Information	Network type
Field	IEC 61850-9-2 IEC 61850-8-1 IEC 61850-90-5	IEC 61850-7-4 IEC 62351-8	Intra-substation
Field-Station	IEC 61850-8-1 IEC 61850-9-2	IEC 61850-7-4 IEC 62351-8	Intra-substation
Station	IEC 61850-8-1 IEC 61850-90-5 RFC 3748 RADIUS	IEC 61850-7-4 IEC 62351-8 RADIUS TACACS	Inter-substation

Zone	Communication	Information	Network type
Station-Operation	IEC 61850-90-2 IEC 61850-8-2 IEC 60870-5-101 IEC 61850-7-104 IEC 62351-8 RFC 3748 EAP RFC 3748 RADIUS	IEC 61850-7-4 IEC 61850-80-1 IEC 62351-8 RFC 3748 EAP RFC 3748 RADIUS	Inter-substation WAN

- **Device remote management system**: It is a system helping system users to manage connection/disconnection/firmware update and maintenance of devices in a system. At the end of 2012, no specific standard was supporting such features.
- **Weather forecast and observation system**: it refers to the system and all elements needed to perform weather forecast and observation calculation and to distribute the calculated geospatially referenced information to required systems, such as distribution and transmission management systems, DER/Generation management systems, EMS or VPP systems for DER, etc. enabling optimized decision processes or automation. It generally consists in a secured IT system, usually relying on SOA infrastructure, possibly interconnected to international weather observation and/or connected to a number of sensors.

Table 33. Weather forecast and observation systems communication and information

Zone	Communication	Information	Network type
Enterprise-Operation	Web services	WXXM WMO METCE	Intra control/data centre Enterprise

7.3.4.2 **E-mobility (connection to grid) mapping on SGAM**

The e-mobility comprises all elements and interfaces which are needed to efficiently operate EVs as a flexibility resource in a future smart grid system.

The standardization work within this domain is leaded by the E-mobility coordination group (EM-CG) and a working group for Smart Charging was specifically built to define role model, associated use cases and identify standards. The results of the work where published in [71] and they will be presented below.

Smart Charging is defined as the charging of an EV controlled by bi-directional communication between two or more actors to optimize customer requirements (energy price, SOC, park time), grid management (e.g. power system constraints) and energy production, including renewables (energy mix), with respect to system limitations, reliability, security and safety.

Besides Smart Charging there is also "Value Added Service", like location and reservation of charging spots that might interact with Smart Charging sequences in several ways.

Key to achieve Smart Charging is interoperability between actors, e-mobility and smart grid technologies.

Three types of load control may be considered:

- Unconditional charging: the battery management system (BMS) determines by itself the load profile.
- Charging with demand response (open loop): the charging is controlled using price signal.
- Smart Charging (closed loop): the charging is controlled by price and technical signals in relation to a combination of constraints from the network.

A control management based on incentives or contract based control signals tries to bring the following benefits for network operation and environmental impact:

- Congestion management and re-dispatch
- Disturbance management and system restoration
- Load shape management for preventing overload
- Balance keeping on local and regional area
- Implementing central and dispersed Renewable Energy Sources (RES)
- Power quality improvement
- Reducing energy losses
- Avoiding unnecessary investments in grid and electricity generating plants
- Reducing ecological footprint (of the whole chain)
- Reliable power system

The control management system may work on time scales which vary form days to milliseconds.

Two options for public charging are considered about electricity purchase and billing, which determines metering and data transmission organisation:

- Energy retailer chosen by the EVSE operator
- Energy retailer chosen by the EV customer or by his service provider

Depending on the business model different types of data should be transmitted:

- Time connected to the charging spot or parked
- Fleet owners might require not billing but only authorisation
- Loyalty cards may involve other information to be transmitted
- Free energy might not require any authentication nor billing

A role model, based on that developed by ENTSO-E, EFET and ebIX for the wholesale and retail markets, is proposed by the e-mobility working group and presented in the next figure.

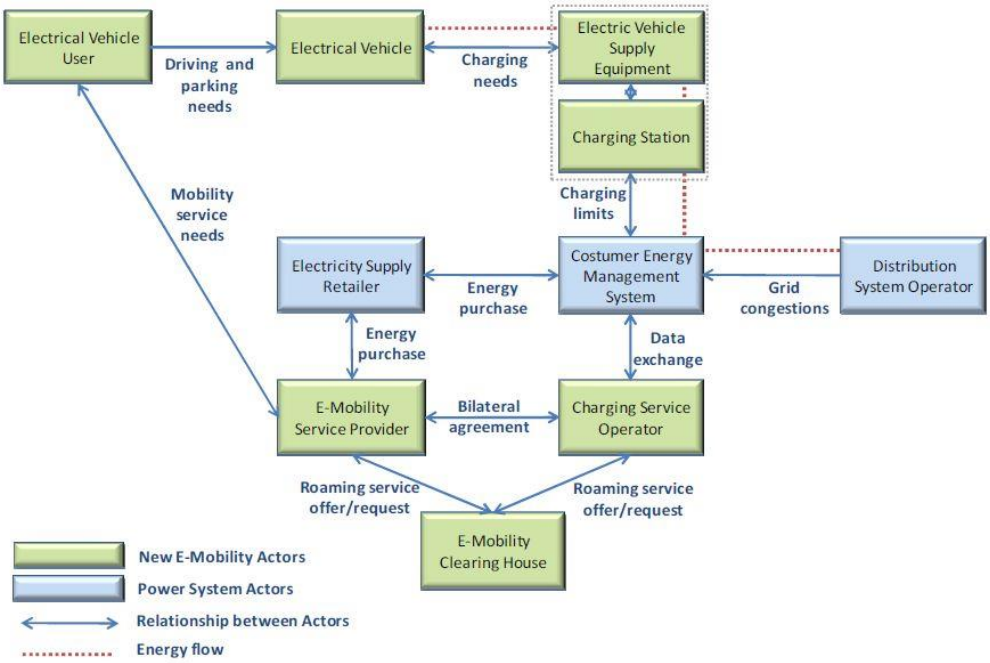


Figure 85. EM-WG role model [71]

Depending on the level of detail for the role model, one party can have several roles. The role model represents the external intended behaviour of a party, therefore, it defines actors and their interrelations.

The SGAM mapping of e-mobility was carried out in the same reference.

The component layer has three aggregation levels:

1. Unit level: EVSE and RTUs in the field zone
2. Station level: aggregation level automatically managed by systems based on signals and measurements from the unit level. A typical example could be a parking house.
3. Operation level: it is the highest aggregation level, where energy management, aggregation of metering and regional congestion management is performed. The operator in the enterprise zone is a trader on energy markets.

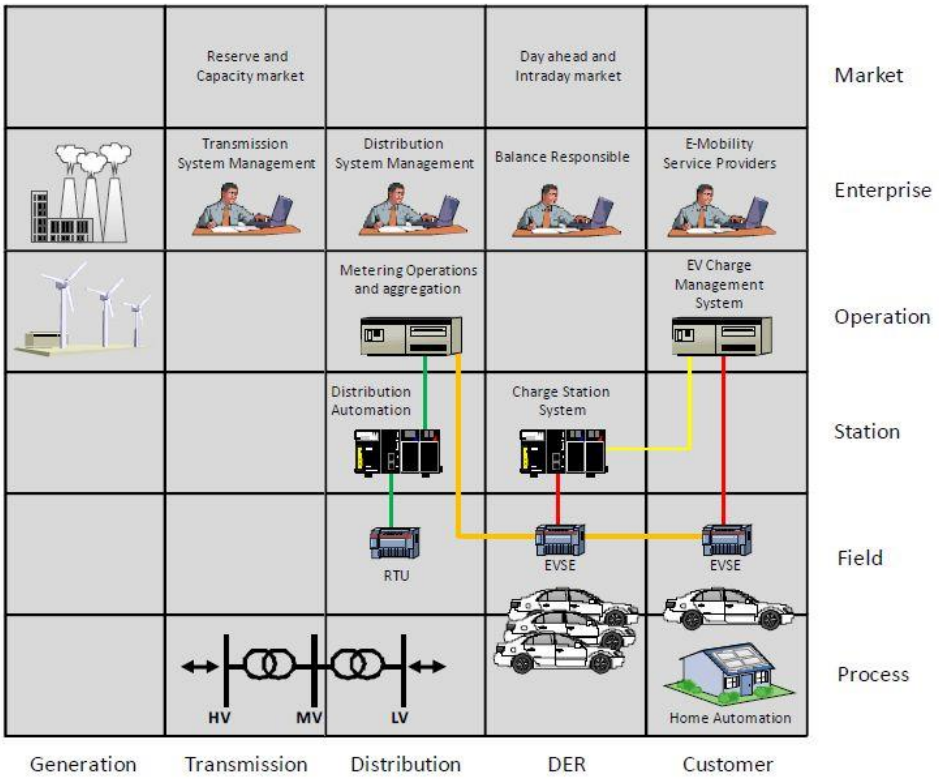


Figure 86. E-mobility - Component layer [71]

Regarding communications, different protocols are relevant from IEC, ISO, ETSI, ITU, and SAE depending on the zone and domain of the SGAM:

- Field zone: communications between EV and EVSE. Standards: IEC 61851-1 (SAE J1772) (PWM) and ISO/IEC 15118-2 (XML - EXI TCP/IP)
- Station zone: it is divided in three domains:
  - Metering: IEC 62056 (DLMS/COSEM)
  - Power grid: IEC 61850, ISO 9506 (MMS)
  - Charge spot: ETSI TS 101556-1 (ASN.1) and OCPP (XML/SOAP)
- Operation zone: communications between operators, mainly CIM standards like IEC 61968 and IEC 61970 based on XML TCP/IP.

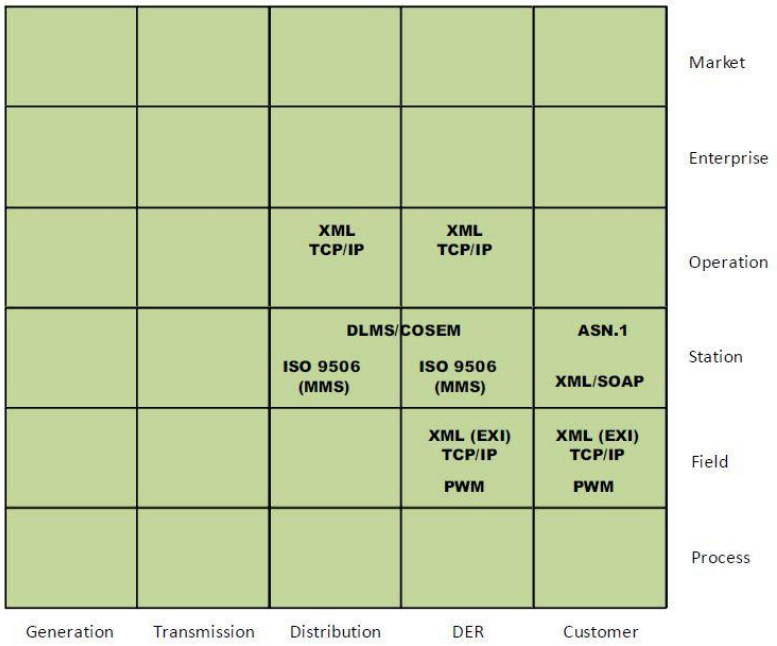


Figure 87. E-mobility - Component layer [71]

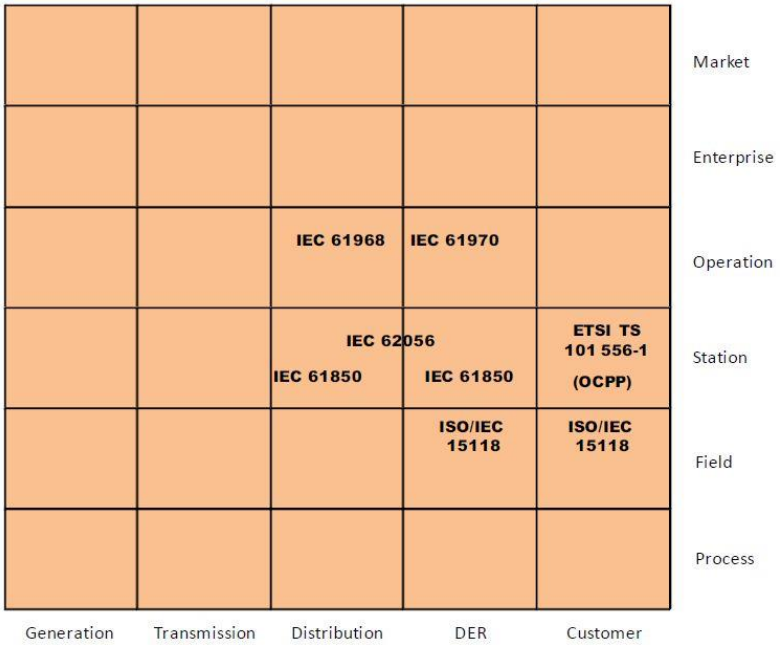


Figure 88. E-mobility - Information layer [71]

If CEN-CENELEC focus group approach is considered (CEN-CENELEC Focus Group on European Electro-Mobility [6]), Figure 1 is the reference for relevant communication standards description. The main communications to be considered have already been indicated above and they are further described below according to the interfaces defined in that figure [6]:

- **A interface:**
  - AC charging:

        - IEC 61851-1 Annex A: basic communication using a control pilot circuit and PWM modulation through a control pilot wire (mode 3 charge), which allows the charge spot to signal the available electric power to the EV. The other option described by this standard in Annex C, which combines high and low level communication without the use of a pilot wire, have not been adopted by the majority of OEMs.
        - ISO/IEC 15118: high level communication using IP, which could be deployed for more advanced services, such as charging schedule. Wireless charge is also being considered in some parts of the standard.
    - DC charging: to ensure a sufficient level of safety at high power levels, the EV controller and the off-board charger controller must exchange charging control parameters with low latency (within milliseconds) and high reliability. Relevant standards:
        - IEC 61851-23: general requirements on the DC EV charging station.
        - IEC 61851-24: Digital communication between a DC EV charging station and an electric vehicle for control of DC charging. The exact relation between IEC/ISO 15118 (general communication services for charging, including identification and authentication) and IEC 61851-24 should be clarified. The possibilities to use the PLC for high power DC charging must be validated. CAN is also considered by this standard as a possible physical layer.
    - When services have to be paid by the EV subscriber, there is a need for identification although alternatives may exist: electricity cost included in the parking fee, free charging, residential charge, etc. The Focus Group recommends a global standardization covering the identification numbering for the contract ID/ subscriber ID and maybe the EV and the electricity meter provider to allow roaming. For this purpose, current standards within telecommunication, security or ITS may be used for electromobility.
- **B interface**: high level communication data channels may use alternative paths such as radio frequency transmission. Cooperation between intelligent transport and electro-mobility standardization is advisable in this matter.
- **D interface**: data supplied by the EV user directly to the charge spot, may use several means: keyboard input, RFID, NFC, credit card, etc.

The other interfaces were not directly treated by the Focus Group and communications between the charge spot and the rest of the grid is considered to be treated and coordinated by the European Standard Organisations (ESO) Smart Grid Coordination Group. The separation between data communication for the legal metering responsible parties and the parties that will manage charging will allow for open market concepts and cross-border interoperability.

The main recommendations from the Focus Group on communications were the following [6]:

- End-to-end scenarios should be considered between involved ESOs in order to achieve harmonised and interoperable link between the different communication standards for electromobility, security, safety and ITS (Intelligent Transport Systems).

Co-operation on data communication and data security between EV, smart grid and ITS is needed.

- Electro-mobility-to-infrastructure for data communication and data security should be defined.
- Electro-mobility control signal and control pilot signal related communication should be defined.
- Conformance tests and implementation guidelines between the different domain areas should be established.
- Standardization is required for the diagnosis protocol, human machine interface and energy management system for the complete charging system.
- Standards work should be established around the concept of "interoperability hub" (clearing house).
- The work done in the EC Smart Grids task force should be expanded to create a security architecture also taking into account issues in relation to the interoperability hub and security issues.

In the US other protocols such as the SEP2, OpenADR and DNP3 could be relevant.

To map the function layer, technical use case elements are described. These will be the link between information and business layers:

- Field zone: ISO/IEC 15118-1 describes a list of use case elements (begin of charging process, communication setup, certificate update or installation, Authorisation)
- Station zone: technical use cases can depend on the domain (metering, power system and charging spot). An example from power system standards is the control of inverters in DC charging according to the TR 61850-90-7 (connect/disconnect from the grid, adjust power factor, available VAr support mode with no impact on W, charging by voltage)
- Operation zone: technical use cases for DSM and EMS could be defined by TC57 WG13 and WG14, but also WG17 for DER. For technical use case elements regarding management of the charging spot it would be responsibility of ETSI and OCPP/OCHP.

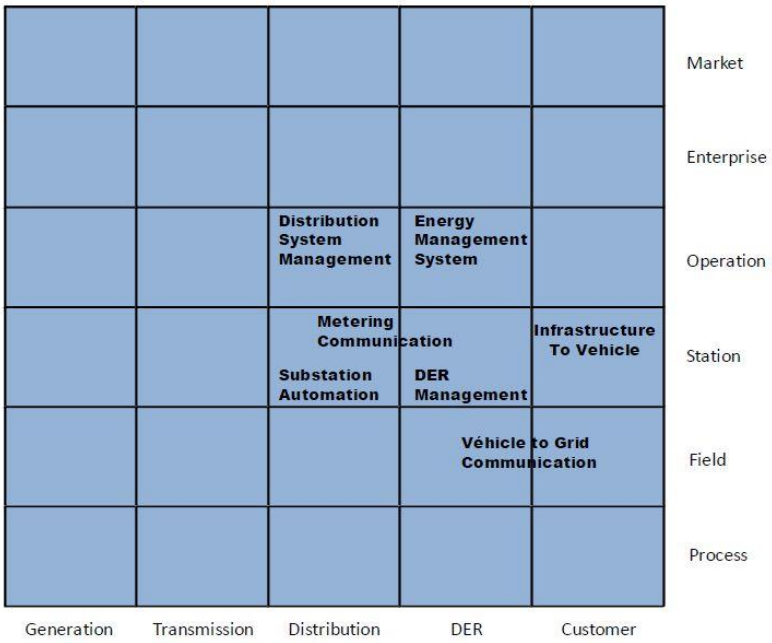


Figure 89. E-mobility - Function layer [71]

The business layer gives an overview of the business oriented use cases and regulations. The report [71] is aligned with [7], which defines basic use cases:

- Field zone: basic use cases for uncontrolled charging, charging with demand response and Smart Charging.
- Operation: basic use cases for manage charge infrastructure and interoperability settlement.

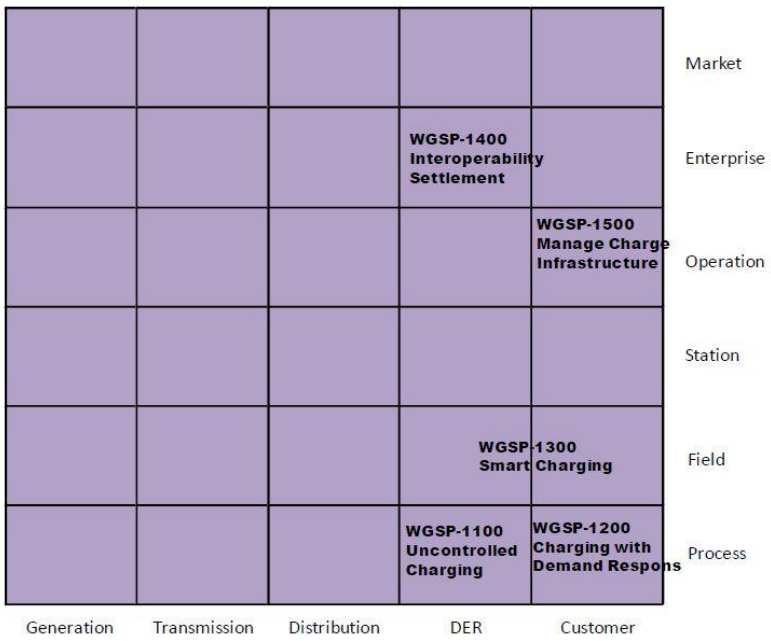


Figure 90. E-mobility - Business layer [71]

7.3.4.3 **Cross cutting technologies**

Telecommunications

A telecommunication service is any service provided by a telecommunication network through a communication system.

The Official Journal of the European Union publishes regularly the titles and references of the harmonized standards under the directive 95/05/EC. These are used for presumption of conformity.

For smart grid communication, products based on specifications from industry (e.g. the IETF, IEEE, W3C) are widely deployed, notably in the area of IP protocols and web services.

The following network types, used in the previous section to describe communication layers, could be defined for smart grids [8]:

- **(A) Subscriber access network**: those that provide general broadband access for the customer premises.
- **(B) Neighbourhood network**: networks between distribution substations and end users. These networks may service metering, distribution automation and public infrastructure for EV charging, for example.
- **(C) Field area network**: networks at the distribution upper level tier, which integrates the various sub-layer networks and provides backhaul connectivity in two ways: directly back to control centres via the WAN or directly to primary substations. It also provides peer-to-peer connectivity or hub and spoke connectivity for distributed intelligence in the distribution level (links station and operation zones).
- **(D) Low-end intra-substation network**: network inside a secondary substations. It usually connects RTUs, circuit breakers and different power quality sensors.
- **(E) Intra-substation network**: network inside a primary substation. It is involved in low latency critical functions such as remote protection. It may comprise from one to three buses: system bus, process bus and multi-services bus.
- **(F) Inter substation network**: networks that interconnect substations with each other and with control centres.
- **(G) Intra-control centre / Intra-data centre network**: networks inside two different types of facilities in the utility: utility data centres and utility control centres. They are different networks since control centres have different real time operation requirements.
- **(H) Enterprise network**: enterprise or campus networks as well as inter-control centre networks.
- **(I) Balancing network**: networks connecting generation operators and independent power producers with balancing authorities and networks that connect balancing authorities with each other. In some emerging cases, balancing authorities may also dispatch retail level DER or responsive load.
- **(J) Interchange Network**: they connect regional reliability coordinators with operators such as transmission operators and power producers, as well as networks that connect wholesale electricity markets to market operators, retailers and traders.
- **(K) Trans-regional / Trans-national network**: networks that interconnect synchronous grids for power interchange, as well as emerging national or even continental scale networks for grid monitoring, inter-tie power flow management, and

national or continental scale renewable energy markets. Such networks are just beginning to be developed.

- **(L) Wide and Metropolitan Area Network:** networks that can use public or private infrastructures. They inter-connect network devices over a wide area (region or country) and are defined through SLAs (Service Level Agreement).
- **(M) Industrial Fieldbus Area Network:** networks that interconnect process control equipment mainly in power generation (bulk or distributed) in the scope of smart grids.

The figure below provides a mapping of the different smart grid networks to the SGAM model.

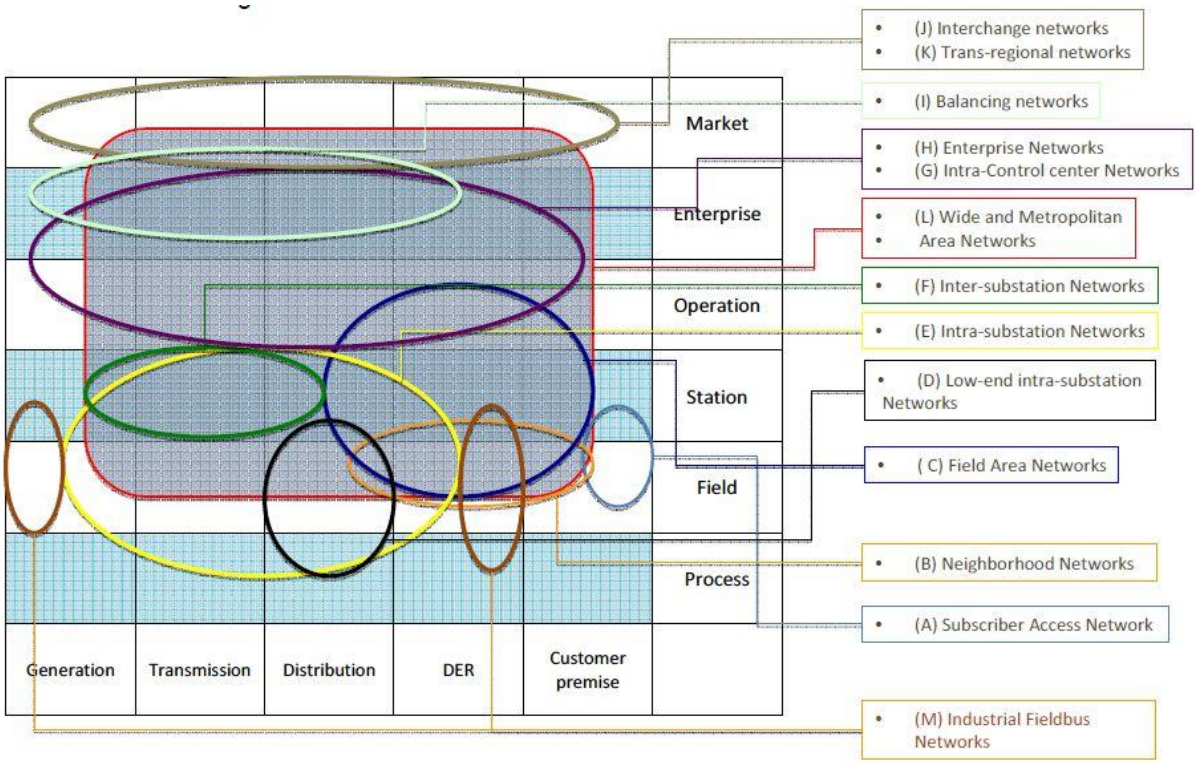


Figure 91. Mapping of communication networks on SGAM [8]

The following table indicates the standardized communication technologies applicable to the smart grid sub-networks defined above. The selected technology for a real implementation will have to consider all deployment constraints. AMI related standards should be checked in TR 50572 [70].

Table 34. Applicability of communication technologies to the smart grid sub-networks

	A	B	C	D	E	F	G1	G2	H	I	J	K1	K2	L	M
Narrow band PLC (LV&MV)	x	x	x												
Narrow band PLC (HV&VHV)					x	x									
Broadband PLC	x	x													
EN 14908 (Lontalk)		x	x												

EN 50090 (HBES)		x	x												
IEEE 802.15.4 (LR WPAN)	x	x	x												
IEEE 802.11 (Wi-Fi)	x	x		x	x										
IEEE 802.3/1 (Ethernet)				x	x		x	x	x						x
IEEE802.16 (WiMAX)	x	x	x												
ETSI TS 102887 (smart metering wireless access)		x	x												
IPv4	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IPv6	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
RPL / 6LowPan	x	x	x												
IEC 61850		x	x	x	x	x								x	
IEC 61870-5				x	x	x								x	
GSM / GPRS / EDGE	x	x												x	
3G / WCDMA / UMTS / HSPA	x	x					x	x	x	x	x	x	x	x	
LTE / LTE-A	x	x	x	x		x	x	x	x	x	x	x	x	x	
SDH / OTN	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
IP MPLS / MPLS TP	x	x	x	x	x	x	x	x	x	x	x	x	x	x	
EN 13757 (M(eter) Bus)		x													
DSL/PON	x	x				x								x	
Higher layer comm. protocol	x	x	x			x	x	x	x	x	x	x	x	x	

G1: Intra-control centre, G2: Intra-data centre, K1: Trans-regional, K2: Trans-national

The First set of Standards document [8] provides a list of standards that reference communication protocols (mostly focusing OSI layers 1, 2 and 3) for smart communications.

Among higher layer communication protocols, smart grid applications and standards rely heavily on web services. Two major types of web services can be distinguished:

- RESTfull Web Services (Representational State Transfer): applications are fully defined via representations (e.g. XML) of resources that can be manipulated using a uniform interface that is composed of four basic interactions: CREATE, UPDATE, DELETE and READ. Each of these operations is composed of request and response messages. The most common implementation is HTTP, others are CoAP and XMPP.
- SOAP/RPC based Web Services: applications expose interfaces that are described in machine process able format, WSDL. These messages are often transported over HTTP and encoded using XML.

Standards related to Web Services as a general technology have been issued by W3C (XML, Web Services in general, SOAP, WSDL), IETF (HTTP, Web Services in general, XMPP), OASIS (SOAP) and ETSI (REST).

Other more system specific solutions like MMS/ACSE are part of relevant standards (e.g. 61850-8-1). Also the specific usage of web services is defined in the IEC 61968-100 (implementation profiles for the application of the other parts of the IEC 61968 using common integration methodologies, including JMS and web services) and the upcoming IEC 61850-8-2 (Mapping to web services).

Cyber security

The SG-SG/SGIS group identified the following documents as relevant in this field:

- ISO/IEC 27001:2013 - Information security management
- ISO/IEC 27002:2013 - Information technology — Security techniques — Code of practice for information security controls.
- IEC 62351 series - Power systems management and associated information exchange - Data and communications security.
- NERC/CIP (Critical Infrastructure Protection): US standard
- NISTIR-7628: US guidelines for Smart Grid cyber security

The next figure shows the landscape in 2012 with the above considered documents.

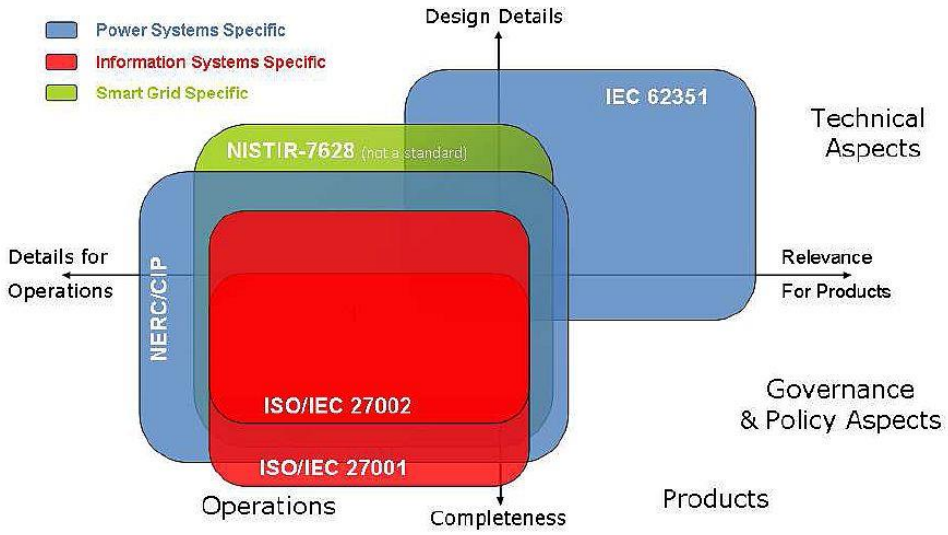


Figure 92. Information security standard landscape [8]

According to this, the standards needed to establish the basis of the smart grid information security are available but there is a need for additional standards to integrate smart grid specific needs. The scope of the analysis was to identify gaps and present recommendations for future standardization in the field.

EMC & Power standardization

Electromagnetic compatibility (see Subchapter 0) is a prerequisite for all applications and products and it is governed by Directive 2004/108/EC. For the smart grid to operate properly and coexist with other systems, it must be designed with due consideration for electromagnetic emissions and immunity.

It shall be consistent with EN 61000-2-2 (LV) and EN 61000-2-12 (MV) standards. For a number of smart applications, such as the EV or PLC in the metering domain, EMC will be a major issue. This will then include compliance with the EN 61000 and 550XX series, besides specific product standards.

When equipment operating in the frequency range 9 kHz to 400 GHz exists, the user shall also comply with the emission requirements in EN50011, EN 55022 or EN 55032. In terms of immunity, IT equipment shall comply with the requirements of EN 55024 or prEN55035.

The standardization work monitored under M/490 identified some gaps:

- Immunity and emission in the frequency range from 2 kHz to 150 kHz.
- Power quality in smart grid context.
- Immunity and emission requirements applicable to DER.

Functional safety

Functional safety approach can provide for each targeted system within smart grids, methods and tools to analyse the new risks attached to any type of unexpected events, to identify possible causes, to evaluate their impacts and to estimate their probability of occurrence and finally to evaluate the efficiency of mitigation solutions.

EN 61508 standard series and possible companion standards are key to support this approach.

7.4 SG-CG Sustainable Processes use cases

The use cases proposed by the SG-CG will be presented in the present section [7]. These should be considered as basic reference and, for new use case definition, the presented methodology should be observed. Most of these use cases come from stakeholder's pilots, demos and further experience in the smart grids field, including e-mobility.

The general objective of the SG-CG's work on use cases is to gather requirements of functionalities in a structured way. They are the basis for the definition of requirement in different standardisation fields (gap analysis).

Other sources for use case definition are standards. This will be tackled in the next section dealing with communication and information protocols.

7.4.1 Use case structure and definitions

A template is used to help describe, compare and administrate the use cases. It contains the following information:

- Administrative: e.g. version management.
- Description of functions: general description, pictures, detailed description
- System under discussion and its design scope
- Actors linked to the function and activities
- Extended information for classification of the use cases

A specialized data base, reflecting the template structure, was introduced, the so called Use Case Management Repository (UCMR, https://usecases.dke.de/sandbox). It supports a central administration of all use cases and allows a collaborative work on writing them.

The use case approach is a good methodology for the formal description of different types of functions, processes or systems. From a general perspective, use cases could deal with business processes and business functions. Roles and actors, functions and business models can be mapped to the business and/or function layer of the SGAM. At lower level,

use cases deal more with technical functions. Some definitions on use cases are given below:

- Use case: it describes functions of a system in technology-neutral way. It identifies participating actors, which can be human or systems playing a role within the case. According to their abstraction level and granularity can be described as High Level Use Case (HL-UC) or Primary Use Case (PUC):
    - HL-UC: it describes the general idea of a function and generic actors.
    - PUC: it is a use case implemented in a specific system characterised by a defined boundary (it can be mapped on a defined architecture). A HL-UC might be broken down into one or more implementation possibilities, called specialisations.
- Scenarios: they define different routes within one PUC according to different trigger signals.
- Steps: they are used to describe activities within a scenario in a sequential order (step-by-step analysis)
- Secondary use case: core functionalities used by multiple PUCs.
- Specialised use case: it is used to difference between PUC that are technology neutral and specialised use cases, which are describing specific technologies like a specific protocol.
- Cluster: it represents a group of use cases.
- Generic use case: their description is broadly accepted in standardization and not project or technology specific.
- Individual use case: in real projects, a company might combine generic use cases together with own, individual, company-specific use cases, which are belonging to its knowledge base and its business cases.

The following figure tries to show the relationship between different use cases.

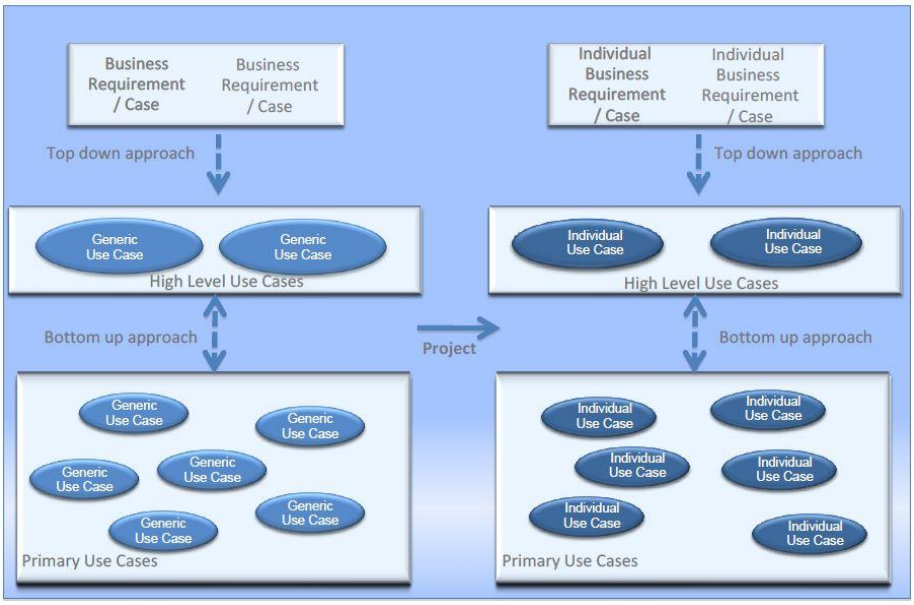


Figure 93. Relationship between Use Case Types [7]

In general, the use case hierarchy cannot be followed strictly, since a PUC can be related to other PUCs or one PUC might serve several high level use cases.

Another example of presenting a mapping of use cases to criteria outside the template is introduced by the report SG-CG/FSS [8]. The report is structured by systems which are defined as follows:

- It is a typical industry arrangement of components and systems, based on a single architecture, serving a specific set of use cases.
- It may be interfaced to other systems.
- It hosts a use case (an abstract HL-UC can be related to various systems).

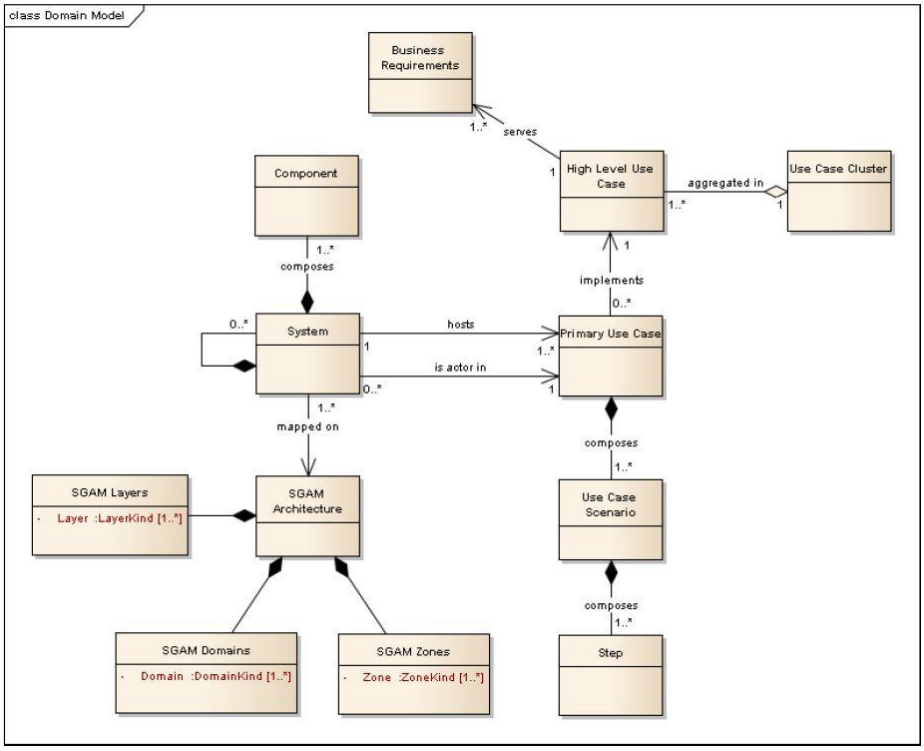


Figure 94. Relationship between Use Case systems and SGAM [7]

7.4.2 Demand and generation flexibility for technical and commercial operations Use Case Cluster

The flexibility concept encompasses the following aspects:

- Demand Response (DR) and Demand Side Management (DSM) as a means to achieve in flexibility in demand, generation and storage: with the first the customer becomes active in managing his/her consumption in return for an incentive payment, with the second the utility decides to implement measures on the demand side to increase its efficiency.
- The customer actively providing flexibility to the market.

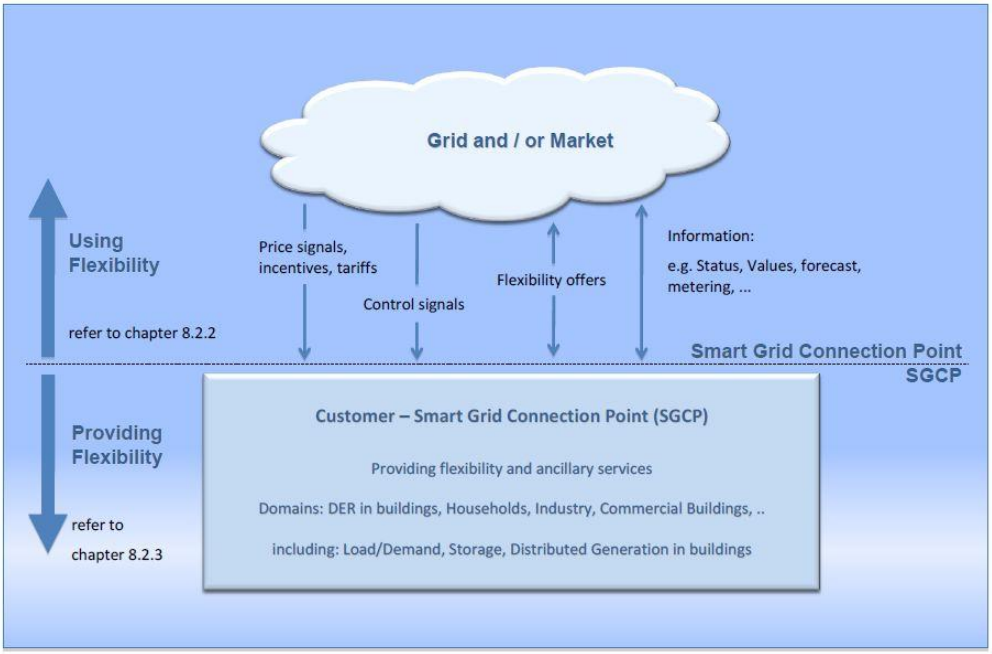


Figure 95. Flexibility - Conceptual Model [7]

Most use cases are describing the DR/DSM together with automation functions on the customer side (Customer Energy Management System). The functional architecture is described by the next figure.

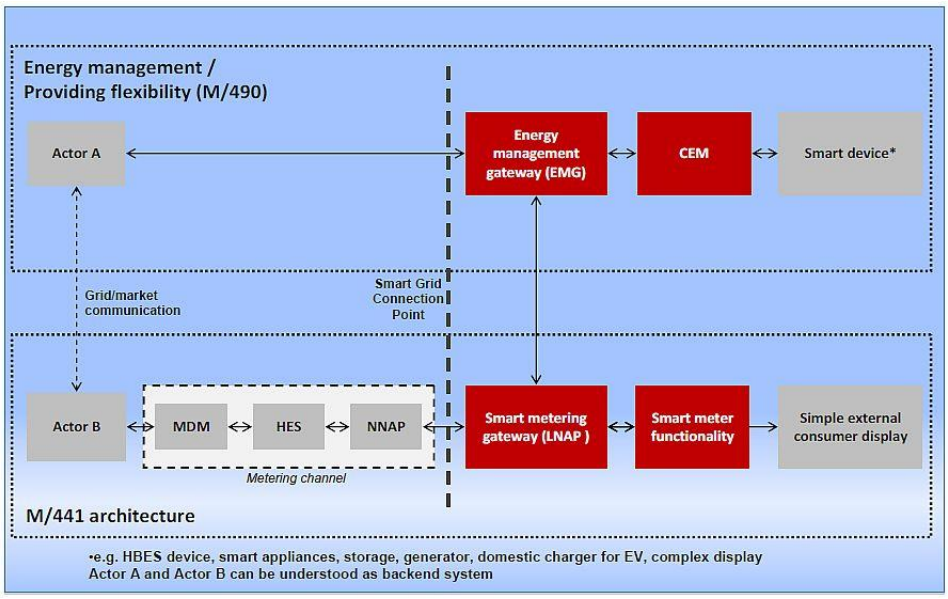


Figure 96. Flexibility - Functional Architecture [7]

The actors in the figure above are functional entities, which means that some of them may be part of the same physical device. In addition, the communication path between the smart metering gateway and energy management gateway is optional (as all communication paths are in this architecture).

Actors A and B represent market roles that could be, for example, a meter data collector, aggregator, supplier, flexibility operator, etc.

This functional architecture can be mapped in the SGAM. Sustainable Processes document [7] proposes the following figure although [8] proposes a slightly different approach.

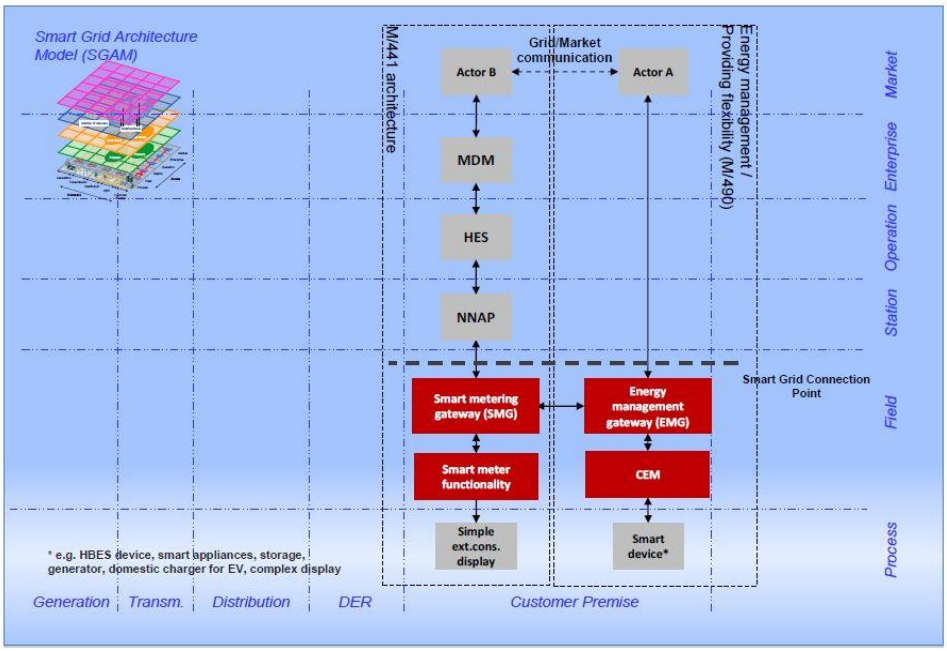


Figure 97. Flexibility - SGAM mapping [7]

The CEM and smart systems might be combined into one device. The first might be also part of other consumption and generation units.

The flexibility provided at the smart grid connection point can serve for both technical and commercial purposes. New market models for flexibility are still emerging and further harmonization and development will be required. A number of possibilities with respect to market design and energy related products influencing flexibility use cases and related ICT interfaces exist.

The use of flexible resources in the power systems can occur over different time horizons and impacts on:

- System balancing: ensuring frequency stability.
- Local network constraint management: ensuring grid capacity is not exceeded.
- Voltage/VAr optimization.
- Network restoration and black start.
- Power flow stabilisation: reducing the variation in power flow across network assets to increase their lifetime.
- Market balancing: reducing deviations.
- Energy market participation: participation of flexible resources in energy markets.

This document [7] introduces the Traffic Light Concept (TLC) in which three steps of grid and market operation are identified:

- Green: the smart market operates freely. Grid or system operator originated incentives (general pricing, location marginal prices, time, imbalance, load factor)
- Yellow: the DSO engages actively with the market in order to keep the system stable. This might be done by offering market participants the opportunity to deliver system support services (the DSO acquires flexibility services). Intelligent solutions and economic incentives should be provided to involve customers. It is a temporary stage.
- Red: the DSO needs to take control of market interactions in a certain area where a constraint has occurred. The DSO can override existing contracts, execute emergency actions through flexibility operators or execute direct controls over generation or demand. Actions in this state must be specific, well defined and temporary.

Some flexibility use cases provided by stakeholders are analysed in the referenced document [7]. They are summarized below:

- Technical flexibility: the primary objective is to stabilize the grid within power quality limits. These functions might be used by other high level use cases like microgrids of Volt VAr optimization.
    - The DSO sends a control request for stability reasons (emergency signals, load shedding, reactive power need, generation increase/reduction).
    - The DSO receives information from, e.g., the smart meter with information regarding power quality outage.
    - DSO provides a correction (price, control) for market priced signals in case of local grid overload (congestion management, yellow situation) or sending a direct command signal (red situation).

Commercial flexibility:

- Energy and balancing power: selling, buying, trading energy (whole sale markets) based on prices in a liberalized market environment; and balancing, after market closure.
- Existing or new markets: day-ahead, intra-day, primary, secondary and tertiary markets using flexibility; and new markets for real time corrections.

The role of the flexibility operator is a general role that pools the small flexibilities of customers (e.g. from CEM) in order to make use of them in the grid or in energy markets. The basic concept of the flexibility operator seems to be widely accepted, although its name and detailed tasks might vary. The flexibility operator might be carried out by exiting market roles like energy suppliers, aggregators, virtual power plant operators, energy services companies, agent, DSO, etc.

7.4.3 Smart Charging Use Case Cluster

EV Smart Charging can help optimize the electricity system through peak shaving, congestion management or renewable integration, therefore, it can be part of other high level of use cases like Volt VAr optimization or flexibility.

The conceptual model proposed for the EV is shown in the following figure. The five high level models identified are included in the blue circles. Five areas are identified in Smart Charging:

- Charge station services: everything related to EV charging.
- Provisioning: Authorization and authentication steps in the charge process.
- Interoperability: between the EV and the charge point including roaming.
- Payment and billing services
- Auxiliary services: all kinds of services related to charging and Smart Charging for EV user, like route and location information services, reservations, energy efficiency optimization, CO_2 reduction mechanisms, etc.

Smart Charging can be classified as follows (Figure 55):

- Uncontrolled (unconditional) or dumb charging.
- Smart Charging:
    - Customer defined charging: maximizing consumer convenience.
    - Grid optimized charging: preventing grid failures or power quality issues, using load control.
    - E-production optimization: optimization of electricity production (peak shaving) using load control.
    - Renewable mix charging: this is related to all previous forms of Smart Charging.

In an EV charging supply chain the following actors are identified: the energy B2B market, DSO, EVSE operator, EVSP and EV.

7.4.4 Generic use cases (GUC)

The generic use cases are available in the UCMR (https://usecases.dke.de/sandbox, name & password: LookatMe). They are originated from different resources: sustainable processes SG-WG, First set of standards SG-WG, information security SG-WG, reference architecture SG-WG, and smart metering coordination group. The use cases might be updated because work is going on.

The suggested generic use cases (GUC) are proposed as staring point. New use cases should be related to them and the existing actor list as much as possible, in order to keep the set of GUCs consistent.

Below, only the use cases proposed by the Sustainable Processes working group will be described more in detail:

- Grid related generic use cases:
    - **Fault Location, Isolation and Restoration (FLIR) - WGSP-0100**: FLIR automates the management of faults in the distribution grid.
    - **Voltage control and power flows optimization (VVO) - WGSP-0200**: automatic control of voltage profile and power flows in active distribution grids with locally connected generators.
    - **Short term load and generation forecasting - WGSP-0301**: load and generation profiles are forecasted for a given period, for example the next day, according to weather forecast, historic load and generation profiles, events, etc. The DSO and the flexibility operator have to forecast generation and consumption in order to monitor and plan network operation or offers respectively.

- **Microgrid management - WGSP-0400**: the microgrid can be islanded from the grid providing electricity supply to its customers for a limited period of time.
- **Monitoring the distribution grid - WGSP-0600**: smart grid devices and their communication possibilities should also be used for better monitoring of the grid on lower voltage levels. This information will be provided in the SCADA system of the DSO and for further evaluation and control.
- **Emergency signals - WGSP-2300**: for emergency situations, the grid operator has a portfolio of options available. This use case describes the option to shut down consumption by intelligent load shedding, via direct load management, if all other options have failed (see WGSP-2120).
- **Electric EV charging:** based on the received cases, five categories have been considered:
  - **Uncontrolled charging - WGSP-1100:** An EV driver arrives at the charge spot, plugs the EV and starts charging. When done, the EV driver unplugs the socket or the charging stops automatically when the battery is full. The only influence on charging is security. Registration might be required depending on the charge spot characteristics.
  - **Charging with demand response - WGSP-1200**: this category provides the possibility to connect the EV at any EVSE and/or with an IEC15118 compliant communication device. The extra communication makes it possible to receive price signals or other incentives so that a customer reaction is possible. The difference with WGSP-1300 is not really clear.
  - **Smart (re-/de) charging - WGSP-1300:** it provides a more controlled way of EV charging. It opens real possibility for Smart Charging and even V2G based on flexible contracts and technical signals for load control. The charging sequence could be as follows: the EV is connected to an EVSE, EV requests charge (including amount of energy and departure time), the charge service provider (CSP) evaluates the request based on contract and technical limitations, CSP informs the customer, B2B market is checked for e-pricing and e-supply availability, CSP requests charge (to the DSO), charging request is evaluated, charge execution is requested, the plan is accepted and executed. Other steps like demand charging plan adjustment for grid constraints or schedule negotiation might exist.
  - **Ensuring interoperability and settlement - WGSP-1400**: it describes interoperability related matters and settlement such as identification, billing, etc. between different actors based on mobile metering.
  - **Manage charge infrastructure - WGSP-1500**: this use case describes the complete system necessary for intelligent charge equipment management, including identification status reports, malfunction management, etc. and for supplying all information for Smart Charging and settlement. It is based in OCPP messages exchange (request and confirmation).

- Flexibility concept related generic use cases:
  - **Receiving consumption, price or environmental information for further action by consumer or a local energy manager - WGSP-2110**: the

objective of this use case is to exchange information between external actors and premises in order to: make consumers aware of their energy consumption; enable customers or their CEM to react on energy prices or others signals; optimize consumption to use cheaper or greener energy; enable external actors to retrieve the state of in-home smart devices; and keep consumption below a certain level. This high level use case comprises four different primary use cases:

- **Exchange information regarding power consumption or generation - WGSP 2111:** The Smart Meter makes available the information on total power consumption or generation in the house. The CEM receives this information but it can also receive individual consumption / generation information per smart device. The rate of update of the information must be proportional to the rate of change in the power drawn. Consumption information can be sent to external actors (A and/or B) or to a consumer display.
- **Exchange price and/or environmental information - WGSP 2112:** Actor A will send information (e.g. price, meteorological, environmental, cost related information, and warning signals) to the consumer or his smart devices via the Energy management gateway; Actor B may do the same via the Smart Metering gateway. The goal is to make the consumer or his devices aware of the amount and cost of consumed energy and of other data (e.g. percentage of green power).
- **Send warning signals - - WGSP 2113:** two scenarios are considered: a warning signal is generated by the smart device after estimating that the power consumed during its next operation will exceed maximum contracted power; and the warning signal is generated by the CEM after noticing that contracted power is exceeded, based on information from the smart meter.
- **Retrieve status of smart devices - WGSP 2114:** This use case describes how an external actor or the customer himself retrieves the state of a smart device directly from the CEM.

- **Direct load/generation management - WGSP-2120:** demand side management signals are sent to the CEM or trigger a programme that manages load by interacting with a number of in-home smart devices connected to the CEM. This high level use case comprises three different primary use cases:
  - **Load/generation/storage management - WGSP-2121:** A load/generation management signal is sent by an upstream actor to increase, reduce or limit the load, generation or stored energy. The CEM can forward the signal directly to the appliance/generator/storage or it may translate it into individual control signals to the smart devices. The smart device may change the power consumption, generation or storage depending on the kind of device, what the device is currently doing and the consumer settings. The CEM may provide feedback to the external actor.
  - **Emergency load control - WGSP-2122**: When there is a risk of a blackout in a given area, an emergency signal from actor A or B can

request Smart devices to turn to network standby according to a safe procedure set by the manufacturer. The signal may or may not contain predefined time duration. The grid may also provide a signal notifying the end of the emergency and the return to normal status. The use case shows how the CEM reacts to this kind of signal.

- Scenario 1: the "emergency load control" describes how a load control signal is sent through the CEM, to the devices.
- Scenario 2: “Announce end of emergency load control” describes how an external actor instructs the CEM that the emergency period is ended. Confirmation from the CEM may be requested.

- **Flexible offerings - WGSP2128:** This use case describes how two market roles offer, accept and assign demand or generation flexibility. On the prosumer level and within its CEM, a flex-offer is bound to one or more devices consuming or producing electricity. It is assumed that flexibility offers are only created in the CEM according to end-user settings (which loads are available, start time and duration of the flexibility period, flexible energy and power). Flexibility offerings are sent from flexibility providers to one or more (potential) users of flexibility. These offerings are negotiated by a process of offering, accepting or rejecting.
- **Auto registration of participating devices and customers - WGSP-2130:** an easy integration of new devices or customers is an essential precondition for smart grids and smart markets:
  - New devices in a household or building register themselves automatically in the CEMS.
  - The CEMS registers the abilities and flexibilities of connected devices automatically and may forward the information towards a flexibility operator, the DSO, aggregator or other relevant market roles.
- **Tariff synchronization - WGSP-2140:** This use case describes how tariff synchronization between a CEM and a smart meter takes place with the scope that both the smart meter and the CEM have the same tariff schedule and know when a new tariff applies.
  - **CEM requests time - WGSP-2141:** it describes how time synchronicity between CEM and Smart Meter is maintained. Two scenarios are possible: The CEM may request the time from the smart meter, based on which the CEM will synchronize its clock; based on time stamped messages from the CEM, the smart meter may notice the former is out of synch, after which the smart meter will send a synchronization parameters to the CEM, forcing it to synchronize.
  - **CEM sends out-of-synch alarm - WGSP-2142:** If the time difference between smart meter and CEM exceeds a certain level an alarm can be raised.
  - **Smart meter notifies active tariff change - WGSP-2143**: the CEM contains the tariff identifier and the price, but does not contain a schedule indicating which tariff is applicable at which time. In this case the smart meter will send a notification to the CEM when the active tariff has changed.

- **Using flexibility - WGSP-2400**: possible generic use cases are indicated in the conceptual description. Traffic light concept.

Several mappings of use cases are possible. The former EG1 of the EC TF Smart Grids provided a list with high level services and functionalities [72]:

A. Enabling the network to integrate users with new requirements.
B. Enhancing efficiency in day-to-day grid operation.
C. Ensuring network security, system control and quality of supply.
D. Enabling better planning of future network investment.
E. Improving market functioning and customer service.
F. Enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management.

The following example illustrates which generic use cases serve which high level services.

Table 35. Mapping example: GUC related to high level services defined by the EG1

ID number	Use case name	High level services according to EG1 (Expert Group 1, 2010)					
		A	B	C	D	E	F
	EV charging	x	x	x	x	x	x
WGSP-1100	Uncontrolled charging	x	x				
WGSP-1200	Charging with demand response	x	x	x	x	x	x
WGSP-1300	Smart (re-/de) charging	x	x	x	x	x	x
WGSP-1400	Ensuring interoperability and settlement	x				x	
WGSP-1500	Manage charge infrastructure				x	x	

In addition, the existing GUCs have to be aligned with the SGAM.

7.5 Summary

The extensive work performed by the Smart Grid Coordination Group on standard identification is a relevant starting point to get an overview of EV and EVSE management possibilities in a smart grid framework.

Even if gaps still exist, published or under development standards can be found in most of the SGAM defined smart grid zones, domains and layers. Their applicability might be currently more relevant for traditional electricity system actors, such as DSOs, but they could also be applicable to new stakeholders, e.g., flexibility aggregators. One of the issues is that some of the published standards are not widely deployed today, sometimes because of their complexity, the implications of upgrading existing systems and functionalities, etc. In many cases, the new functionalities are not considered of high interest for their businesses by stakeholders such as DSOs, at the moment.

EV dedicated standards are also evolving and permitting wider functionalities, however, they are mostly focused on the EVSE - EV domain. Therefore, it might be important to have a look to those smart grid standards that are being developed and used in other domains to check if they can be useful and applicable to EV use cases. For example, aspects defined for flexibility operators or VPP operators systems could be used by EVSPs, administrative aspects or cross cutting issues (communications, security, etc.) might be relevant for most stakeholders, etc.

The state of the art overview performed in this chapter is suitable to be completed with the work performed in COTEVOS task 4.1, dealing with current demonstration activities, which are testing different EV and EVSE charging approaches. For the moment, it seems that different business models, regulatory designs and standards will be deployed and that is expected to happen at least until one or few of the solutions will be able to win relevant market shares.

Demand response seems one of the services that becomes of highest interests, both from the smart grid and the EV (Smart Charging) perspectives. However, there are many ways in which this could be performed, depending on regulatory aspects and DSO strategies, including business models. Just to use demand management as example, it could be stated that smart energy based on ISO/IEC 15118 requires end to end communications and permits a high number of functionalities but, at the same time, it requires smart appliances, communications, back-end application development, etc., which is translated into high costs. A very different example is that of open loop charging, in which end-users decide when to charge based on price signals and, therefore requires lower interoperability level. Results might be different but also investment and operation and maintenance costs are different. An intermediate solution might be that of including EVSE control in an asset control strategy that a DSO might already have, for example through energy management systems or smart meters at homes. Solutions are several and they may well coexist.

Developments have also occurred in the use case definition methodology. There is a standardised procedure to define and present them, which tries to achieve interoperability also at this level. However, the use cases that have been defined up to now in the e-mobility field are far from complete.

Regarding testing, a methodology devoted to interoperability was also presented by the SG-CG. The process is based on profile specification, use case identification and the V-model method. Several initiatives have been launched on interoperability testing but they are normally related to specific standards or systems and harmonization seems to be scarce.

8 NEEDS FOR INTEROPERABILITY BETWEEN EVS AND ELECTRICAL POWER SYSTEM – ASSESSMENT

In the present section, the state of art summarized in the previous subchapters and dealing with smart grids in general will be characterized for the EV case.

All SGAM layers will be looked at but the focus will be set on communication and information protocol description.

8.1 E-mobility Use Cases

As part of smart grids, EVs will be related to many of the defined smart grid systems (Table 19). Apart from specific e-mobility related developments, the following systems will have to take EVs especially into account:

- DER management systems
- Demand and generation flexibility systems
- Administration systems

With regard to smart grid generic use cases Table 20, even if they are mainly considered for traditional actors, such as DSOs, retailers, who will have to manage EVs as additional DER assets (demand in the short term, storage and generation in the future), they may be valid also for e-mobility actors such as:

- EVSE operators: metering aspects (AMI systems), customer management, asset maintenance and monitoring, DER control though asset management, system and security management (rights and privileges management, configuration of new devices)
- EVSPs, aggregators, etc.: metering data management, customer/commercial relationship management, provision of services to the network (demand flexibility), trading front office and back office operation, provision of services to EV users, DER operation (including VPP management)

Three types of load control are considered for EV charge [71]:

- Unconditional charging: the EV (its BMS) determines the load profile (uncontrolled).
- Charging with demand response: the charging is controlled by the user considering a price signal (open loop).
- Smart Charging: the charge is controlled by price and technical signals (close loop). Smart Charging can be further classified depending on the optimization focus [7]:
    - Customer defined charging: it maximizes customer's convenience.
    - Grid optimized charging: it prevents grid failures or power quality issues.
    - E-production optimization: it optimizes electricity production generation.
    - Renewable mix charging: it is related to all previous aspects.

In addition to this three, other two generic use cases (GUC) are added regarding EV charging [7]:

- Interoperability based on mobile metering.

- Charge infrastructure management, which is really a part of Smart Charging dealing with the EVSE upstream communications.

Use cases can define from high level aspects related to business processes or models, actor roles, general functions (business layer), etc. to more detailed interactions such as technical functions (function layer), which should derive from the first by gaining definition in the services comprised within a use case. The next step should be information exchange and communication definition based on the involved components.

The Green eMotion project D3.3 deliverable [75], ISO/IEC 15118, OCPP protocol and the EV user related use cases presented by S. Singh [76] were used as main sources to identify more elementary e-mobility use cases.

Table 36. List of Use cases

Type	Use Case
Charging (ISO/IEC 15118)	Start of the charging process
	Communication setup
	Certificate update and installation
	Identification, authentication and authorization at EVSE or by a Secondary Actor
	Target setting and charging scheduling
	Charging loop
	End of charging process, send charge details
EVSE operation	Modify firmware, configuration, status, reservation
	Get information (meter, diagnostics, configuration, white list…)
	Perform remote control of charge (start/stop charge, send settings…)
EV user services	Search and reservation of EVSE
	Road assistance, emergency notification…
	Billing and sustainability information access
	Vehicle diagnostics and monitoring (SOC for example)
	Vehicle maintenance, firmware and SW upgrade, configuration
	REESS maintenance
	EV user preferences setting before charging: charging options identification and selection (load management included), market place access and service selection
	Contract management
	Remote access to Vehicle: EV interior preconditioning…
	Driving and navigation info update (real time information): traffic, meteo, multimodal transport, navigation, search of points of interest
	Entertainment: news services, social networking, internet radio, internet purchases…
	Car sharing services: vehicle location, reservation and access

Fleet manager services	Fleet tracking
	Fleet monitoring: energy consumption, vehicle diagnostic
	Parcel delivery management & smart logistic
EVSP – EVSE op. services	Roaming: identification, authentication and authorization at the clearing house, message exchange…
	Information exchange: EV users contract, EV related info, mobility, meteo, etc
	Information and service exchange through the market place: communication set-up, identification, authentication, authorization…
Network services	System operators send network information or support request
	EV vehicles provide day-ahead/intraday services to the network
	EV vehicles provide contingency support services to the network
	EV vehicles provide power quality services
	EV vehicles supply electricity to the network (V2G)

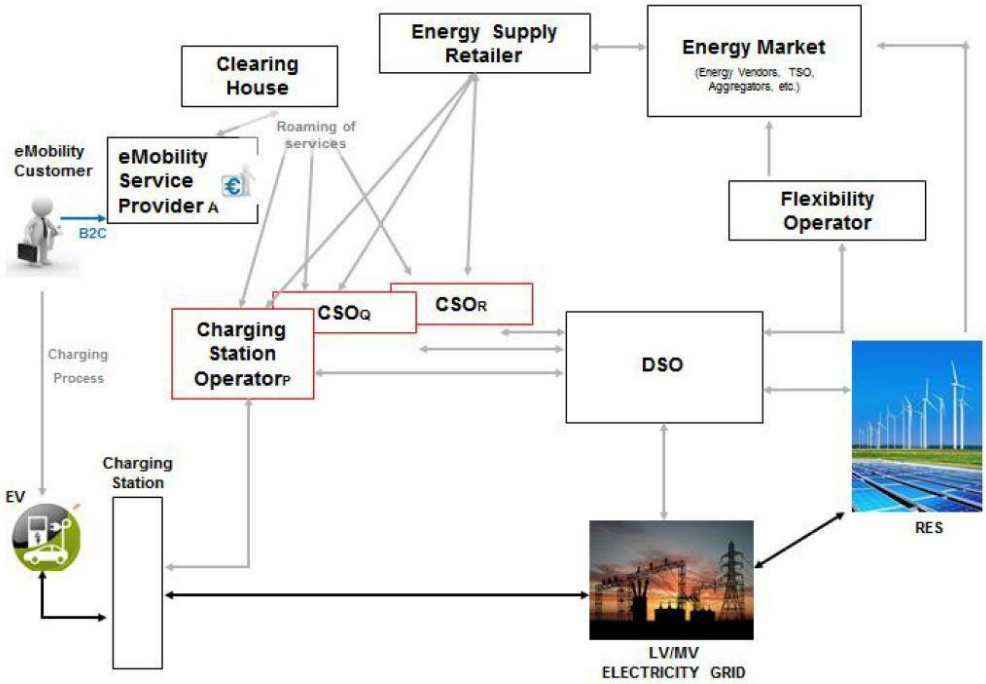
Depending on EV charge **infrastructure category**, the use cases and business model approach might be different, especially for the Smart Charging option. Eurelectric considers four categories [74] :

- Public charging station in public domain (e.g. curb).
- Public charging station in private domain (e.g. shopping malls).
- Semi-public charging station in public or private domains (e.g. car sharing and hotels).
- Privately accessible charging station (e.g. home or office).

In **private accessible charging stations**, Smart Charging is normally foreseen through a CEM system, which would be able to control EV load through a dedicated EVSE or a more conventional smart switch, allowing for different levels of management.

For **publicly accessible charging infrastructure** Eurelectric proposes two approaches [74], direct payment and roaming. For the latter, two possible scenarios are considered:

- **Roaming of charging service**: the electricity supply retailer is chosen by the charging station operator (EVSE operator), which means that the first is fixed at the charging station. The e-mobility service provider has an agreement with the CSO and he bills his customer for a bundled service (electricity and infrastructure fee). This might not be considered a roaming case by some experts since only one EVSP and one EVSE interact.

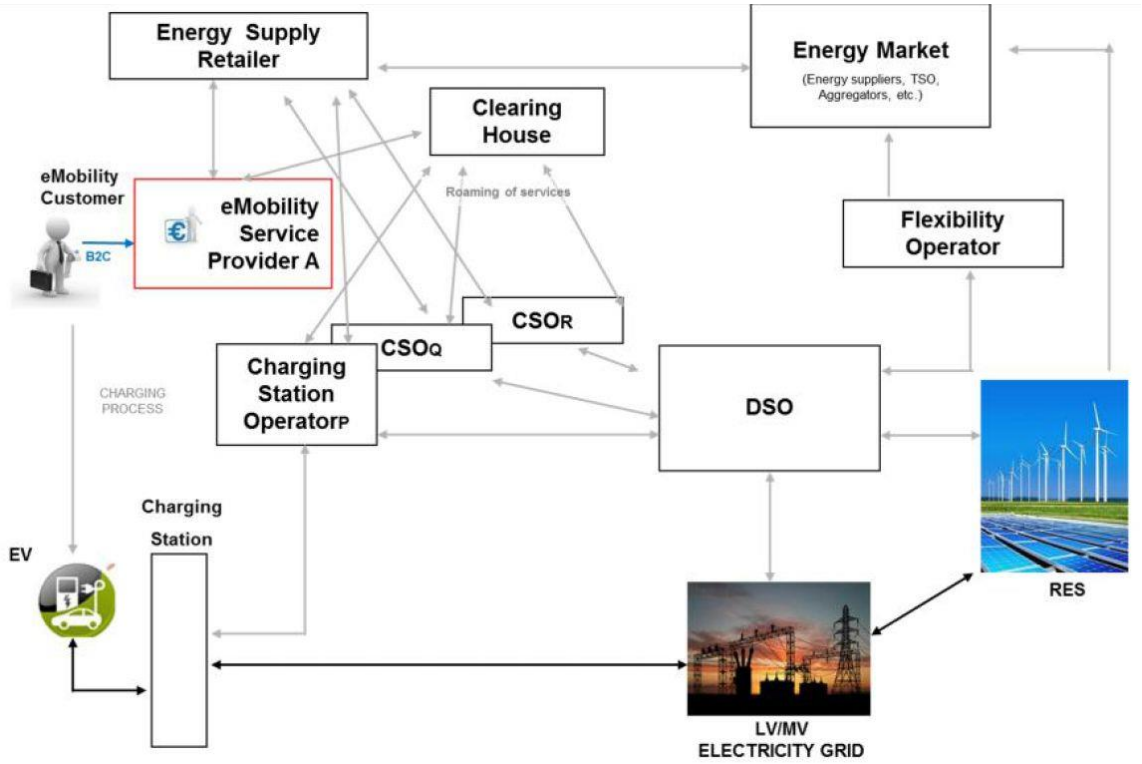


Blue arrow: B2C contractual relationship *Red-line box: final electricity customer*

Grey arrow: B2B contractual relationship *Black arrow: physical connection*

Figure 98. Eurelectric - Roaming of charging service [74]

- **Roaming of electricity and service**: the consumed electricity is purchased from an ESR chosen by the e-mobility service provider. The contract between the latter and the charging station provider does not include the price of electricity but a fee for using the infrastructure. The e-mobility service provider will bill his customer an additional roaming fee for using the public charging station.



Blue arrow: B2C contractual relationship *Red-line box: final electricity customer*

Grey arrow: B2B contractual relationship *Black arrow: physical connection*

Figure 99. Eurelectric - Roaming of electricity and service [74]

Other proposed market or role models for e-mobility are provided by Figure 1, Figure 85 and Figure 100. In the next figure, a model with a market place offering EV services is proposed as additional example.

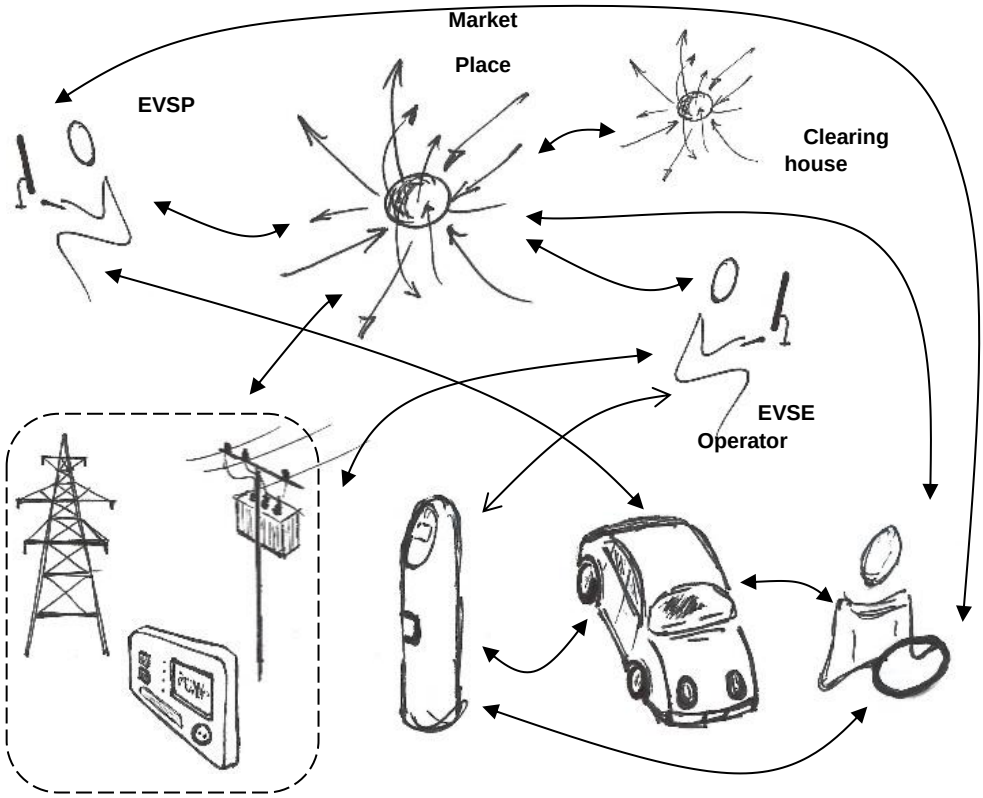


Figure 100. Market model example with market place (source: Tecnalia)

In each role model, actors will offer products and or services. Many stakeholders can be defined and still the most relevant aspect regarding stakeholders is probably the role their play, since market actors might not play the same roles or share the same names in all regulatory frameworks. The following table sums up the most common names for roles and actors in the e-mobility environment.

Table 37. E-mobility actors

Actor names in (WG-SC, 2013)	Actor names in (SG-CG/SP, 2012)	Actor names in other references
Electric Vehicle User (EVU)	Vehicle user	EV customer/user/driver, End customer
E-mobility customer (EC)		EV subscriber
	Vehicle owner	
Electric Vehicle (EV)	EV/PHV	EV
Electric Vehicle Supply Equipment (EVSE)	Charging spot (CS)	EVSE, Charging point/station/spot, EV charging equipment (EVCE)
Charging Station (CS)	Charging spot (CS)	Charging point
Charging Service Operator (CSO)	Charge Spot Operator (CSO)	EVSE operator, Charging Station Operator (CSO)
Electrical installation operator (EIOP)		Private network operator (?)
E-mobility Infrastructure owner (EIOW)	Charge Spot Area Owner	Charging Station Equipment Owner

Actor names in (WG-SC, 2013)	Actor names in (SG-CG/SP, 2012)	Actor names in other references
Customer Energy Management System (CMES)	CEMS (CEM with communications), CEM	CEMS, CEM
E-mobility Service Provider (EMSP)	(e-)Mobility Service Operator	EV Service Provider (EVSP), Charge/ing Service Provider (CSP)
	Fleet operator	
	Parking service operator	
		Navigation Service Provider (NSP)
Electric Vehicle Manufacturer (EVM)	Vehicle Manufacturer	OEM (Original Equipment Manufacturer)
E-mobility infrastructure producer (EIP)		
OEM (Original Equipment Manufacturer)		OEM (Original Equipment Manufacturer)
E-mobility Clearing House (EMCH)		Clearing House (CH); financial clearing processor; data, financial and commercial clearing processor; interoperability hub
E-mobility Clearing House Operator (EMCHO)		Clearing House operator
		Data hub, data clearing processor (without financial or commercial activity compared to a CH)
Energy Market (EM)		Wholesale market, ancillary services market, etc.
Flexibility Operator (FLO)		Aggregator
Electricity Supply Retailer (ESR)	Retailer	Retailer, supplier
Distribution System Operator (DSO)	DSO	DSO, network operator (it could also refer to TSO)

The main actors for e-mobility are further described in the official glossary document of COTEVOS.

8.2 Regulation

Regulation sets up the highest level framework for the development of activities within a region. It has a direct influence on regulated businesses, as those related to the distribution and transmission of energy, but it also builds a framework for private business development.

Regulation should not hinder EV penetration but promote business models and permit their profitability under global sustainability concepts. Strict rules might have as negative impact as the lack of regulatory definition in order to achieve the development of healthy businesses.

At electricity network level, the regulation establishes, for example, the characteristics of the participation of small consumers in electricity markets as well as the role of players,

which affects the development and feasibility of potential businesses. The main aspects covered by the electricity sector regulation having an impact on business are the following:

- **Network operation procedures**: involvement of small DER, implementation of mechanism for the deployment of demand flexibility in operation, etc.
- **Low voltage and building codes**: the LV code defines the basic requirements that infrastructure assets and installations should meet when installed to the low voltage network and, therefore, it has a direct influence in investment costs for final users. In the case of EVs, it is related to charging infrastructure requirements. Building codes may also impose some requirements on infrastructure in residential and industrial buildings, facilitating or obstructing infrastructure development.
- **Electricity tariff definition**: it has influence on final users' behaviour with respect to the deployment of electricity, basically, on how much and when it is demanded. Flat or time of use tariffs, critical peak pricing and real time pricing will cause, presumably, different consumption patterns. Currently, energy tariffs are related to electricity supply business and therefore they are not regulated anymore, however, in some countries they are still an option for smaller customers. Network tariffs remain regulated and they could be used for demand response shaping.
- **Compensation of regulated activity**: system operators' incomes are based on the eligible costs defined by regulation. Among these, the following are quite common: investments, operation and management, marketing, metering activities… This has direct influence on the strategies that systems operators accomplish. For example, the way in which demand response strategies are compensated to system operators will cause them to be considered or not by these and this has an effect on the services that EVs could offer to the network.
- **New actors' definition**: the involvement of small DER in system operation may require the definition of actors aggregating demand, generation or both. These actors should be legally defined and entitled to participate in electricity market or operation mechanisms and the requirements requested to them should not hinder the feasibility of their business model.
- **Market requirements**: market requirements, from the electricity wholesale market to balancing or ancillary services markets, may prevent the participation of small capacity DER, demand, etc. due to cost, technical or administrative issues and, therefore, they might avoid the involvement of some actors in potential business models.
- **Security and environmental aspects**: homologation, EMC or emissions requirements have an impact on EV and infrastructure characteristics and on their commercialisation.

Other more general aspects of regulation, on the top of those mentioned above, have also a great influence on the development of business options:

- **Competence protection**: it is of great importance to allow the access of new stakeholders or business to established markets.
- **Administrative requirements and taxes**: it is of importance especially on starting business since they might represent a burden for their business model.
- **Support schemes or other benefits for final users**: they might be necessary at the beginning in order to help develop a new market.

Market regulation evolution, which may help demand participation increase, requires normally long time implementation periods. Proposals for future markets address the need to:

- Allow demand and small DER participation in system operation and electricity markets to increase system flexibility and resources.
- Link electricity price to electricity cost through variable tariffs and network fees.
- Increase the efficiency and reduce the environmental impact of the different stages of the electricity supply chain and, considering EVs, of the mobility transport.
- Increase the competence in energy markets, especially in some countries.

Until this is achieved, business options for small consumers such as EVs and new stakeholders will be limited from the regulatory framework perspective. Although, modifications might be not expected in the short term they should be considered in our analysis.

An essential characteristic of regulation is its area of applicability. At EU level, EC directives are common for all countries and they should be transposed to national legislation, nevertheless, other rules and requirements exist at national, regional and municipal level. In addition, some countries are not part of the EU but due to their geographical situation, EV interoperability effectiveness is more than recommended. Normally, electricity market particularities will have an impact on:

- **Increased functionality/service availability**: more evolved markets or regulation, in general, allowing a greater variety of services and, as consequence, of potential business models.
- **Increased profitability of business models**: an optimum regulation should not represent a barrier to business model profitability, however, that might happen globally or only for certain business types.
- **Different actors**: some actors might not be defined by certain regulation and, therefore, some business models could be hindered. Some actors might have some competences in one country and others in a different nation.

8.3 Business

The importance of the regulatory framework for the development of business models, in general, and innovative business, in particular, has been already mentioned in the previous section. Even if some areas provide better environments than others for EV business development, current and future market options should be considered.

Consumers' tendency to value losses higher than gains, has already triggered the pursue of innovative businesses able to surface EVs' positive aspects. In this context, service sale (compared to product sale) and solutions based on ICT seem to stand out. Some examples are the following:

- **Alternatives to vehicle purchase**: the high price of batteries and, in general, the total cost of ownership (TCO) of EVs, make especially suitable for EVs leasing (of complete vehicle or batteries) and vehicle sharing services and rental.

- **Infrastructure**: charging is the main service linked to EVs. The charging point location area, private, public or semi-public, leads to different costs, smartness opportunities and competition level options.
- **Interoperability**: roaming may provide transparent and efficient services, comfort for the final user (more available charging points) and a lower level of overall costs (duplication is avoided). Another interoperability option is the deployment of mobile smart meters inside the vehicle, which may require lower infrastructure costs but data clearing from the beginning.
- **Sustainable transportation**: EV is part of a global sustainable approach and, therefore, solutions offering new mobility concepts are starting to appear (combined use of private and public transport, vehicle share, smart logistic…).

Each of this type of business model may involve different information requirements. However, similarities will be also many when we stick to exchange of information between systems and actors, even if these may adopt different denominations.

The main service linked to EVs is related to its charge and the associated business is the energy supply to vehicles. However, this charge might have different characteristics and information requirements depending, basically, on its smartness, interoperability levels and market model. Some options will be shown below:

- **Open access**: the EV user charges at an EVSE without the need of having a contract with an EVSP or EVSE operator. The EVSE operator offers the whole charging service to the EV user and for that it should have an agreement with one or more EVSPs. The EV user could be offered the possibility to choose from a list of charging services offered by different EVSPs at the EVSE. The EV user pays at the spot.
- **Without roaming**: The EV users charge at the EVSEs they are allowed to do so. In this case the EVSE operator and the EV user have an agreement with the same EVSP. The service might also be free.
- **Roaming**: The EV user can charge at the infrastructure of an EVSE operator who has no agreement with his EVSP but clearance, either financial or data, is done through a clearing house.
- **With roaming through a market place**: EV customers charge at an EVSE operated by an EVSE operator who does not have a roaming agreement with their EVSP, but who has a roaming agreement with a market place operator with whom the EVSP has an agreement too.

The information exchange required to perform this charging services depends on each option characteristics. The open access will need less information because it involves fewer actors during the charging process (EVSE operator and EV user) and may not require identification beyond established processes (credit card payment, for example). Roaming involves the clearing house, and the market place adds a new actor but it might simplify operations by centralising exchanges. By adding smartness to the charging process other actors (network operators) and services (electricity price information, vehicle information, etc.) are included in the procedure.

8.4 Components

The definition of components is derived from the use case information on actors, since these can be of different types: devices, applications, persons and organizations.

Table 21 presents a comprehensive list including smart grid components. The following table shows a selection of those more directly related to e-mobility while proposes a link with several actors/roles.

Table 38. Roles and their related systems

Roles/actors	Related systems
EV user	HMI platforms, EVSE, computer, smart phone, charging control, Customer energy management system, energy management gateway, load controller, meter, smart plug, Plug-in EV, etc.
EVSE operator	Asset management, Demand response management system, Building/customer management system, Energy management gateway, GIS, HES, charging station (EVSE), meter data concentrator, SCADA, charging/load control, billing, etc.
EVSP*	Customer information system, customer portal, billing, Demand response management system, energy trading application, enterprise resource planning, front-end processor, GIS, meter data management system, asset management, Load controller, etc.
Market Place operator	SW platform permitting access and operations Energy market management, registration application, settlement
Clearing House operator	SW platform permitting clearing house services Energy market management, registration application, settlement
Network operators (DSO, TSO)	SCADA, Charging station (EVSE), DER control, Demand Response Management system, front-end processor, GIS, HES, energy market management (ancillary services)
Energy retailer	Customer information system, customer portal, energy trading application, enterprise resource planning, billing, etc.
Metering operator	AMI Head End, Meter data concentrator; meter data management system, etc.

* Different systems depending on the services offered by the EVSP: energy provider, aggregator, OEM, etc.

8.5 Information data models

Data models are specified normally by communication protocols.

The most relevant communication protocols specific for EVs defining information data models are the following:

- **IEC 61851-1**: it defines the control pilot function that allows one-direction communication (from EVSE to EV). According to this specification, load management options are linked to a dynamic limitation of power through the EVSE. The IEC 61851-24 deals with DC charging communications.
- **ISO/IEC 15118 series**: two way communications are made possible (also from EV to EVSE) and the negotiation of the charging schedule of the vehicle is considered. This set of standards is focused on EV – EVSE communications but secondary actors' roles are also mentioned, therefore, data exchange extrapolation to EVSE upstream levels might be required. Not all parts of the standard are published currently.
- **OCPP**: it defines EVSE upstream communications.
- **CAN SAE J1939**: EV automotive communication network among vehicle components including EV HMI, vehicle body computer, e-drive, REESS, vehicle charging inlet interface for EVSE, all vehicle electronic equipment

Standardization efforts are taking place currently, as those lead by the EMI[3] group. Careful attention should be paid to their developments as well as to the new publications and version of above mentioned standards.

On the other hand, standards deployed in the smart grids and ITS frameworks should be considered since end-to-end interoperability is necessary in e-mobility related processes. The following standards are analysed below:

- Electricity network standards: IEC 61850 (Power Utility Automation), IEC 61968 and 61970 (Common Information Model -CIM- for Distribution and Energy Management), IEC 60870-5 (Transmission protocols for telecontrol equipment and systems).
- EV related communication standards: IEC 61851-1, ISO/IEC 15118, OCPP, OCHP, and SAE J1939.
- ITS standards: ETSI TS 101 556-1 (EV charging spot notification specification - ITS).

Others, such as web services, are currently very used for information exchange between smart grid applications. Some more specific solutions related to web services are becoming part of relevant standards (IEC 61850 and IEC 61968).

8.5.1 IEC 61850

IEC 61850 and communication

DSOs and Smart Grid Strategic Group sees high potential in the further IEC 61850 expansion.

IEC 61850 is a set of standards applicable for the design of electrical substation automation for electric power systems. The abstract data models defined in IEC 61850 can be mapped to a number of protocols, running over TCP/IP networks and/or substation LANs using high speed switched Ethernet to obtain the necessary response times below four milliseconds for protective relaying. IEC 61850 was identified as a core standard for smart grids.

IEC 61850 enables continuous communication from a control station to decentralized energy generators by using a standardized data format. It enables interoperability between devices of different manufacturers by exchanging a set of clearly defined data and the

devices can interpret and use these data to achieve the functionality required by the application due to a standardized data model.

IEC 61850 addresses the data exchange on three levels: process level, field level, and station level. It supports the direct exchange of data between IEDs, thus enabling switching interlocks across feeders independently of the station control unit. IEC 61850 also provides benefits in the areas of engineering and maintenance, especially with respect to combining devices from different vendors. Currently IEC 61850 is extended for use outside substations, e.g. also in non-electric domains (e.g. gas and water supply).

With the extension of IEC 61850 for communication to the control centre and communication between control centres and sub-stations (based on 61850), there are overlaps in the object model between IEC 61970 and IEC 61850. Currently no complete mapping exists between IEC 61850 and IEC 61970. ZSDis/E.ON as DSOs focus on an effective transportation and adequate bandwidths.

Glossaries and data modelling between the control centres (CIM-based) and the field application (IEC 61850) are not aligned, and this gap is leading to additional complexity, and reduces reliability and upgradeability of concerned systems.

There is a necessity to harmonize IEC 61968, IEC 61970 and IEC 61850 series. All these series have been identified as core standards for smart grids by IEC with high impact on operation, complexity, reliability and upgradeability of concerned systems. Harmonization will provide significant improvement on interoperability and data exchange between the different applications used by DSOs, reduced inter-applications interface development and engineering effort and reduced database import, migration and maintenance efforts.

From DSO point of view, the missing alignment of glossaries and data modelling between control centres and field application may cause additional complexity and reduce reliability and upgradeability of concerned systems. Therefore DSOs warmly welcome the efforts to harmonize the smart grids core standards IEC 61968, IEC 61970 and IEC 61850 series.

IEC 61850 and AMI

The bi-directional communication network between the smart grid and metering devices and business systems allows collection and distribution of information to customers, suppliers, distribution network companies, utility companies and service providers. This enables these businesses to either participate in, or provide, demand response solutions, products and services.

Advanced Metering Infrastructure (AMI) combines metering and management of distribution networks in one system. As a Smart Grid solution it acquires data and information on prosumers, special contract customers and the distribution network infrastructure and transmits them to a control centre. This allows distribution network operators to optimize essential key processes and offers new services and data to their customers, both on the supplier as well as the consumer/prosumer side. Providing monitoring information to distribution network operators AMI facilitates them to control energy supply to a steadily growing number of prosumers, and to ensure better power quality.

The main problem in AMI is the existence of a number of parallel and even conflicting standards. Subsets of common semantics must be defined. The question of how to describe

a common set of cross-cutting requirements within these standards to facilitate exchange of confidential and authentic information across standards must be solved. Regarding the IEC standards alone, the current protocols and data exchange standards (DLMS/COSEM) are concentrated on meter data exchange with Advanced Meter Reading (AMR) units and do not fulfil all the requirements posed by Smart Grid. This includes functions such as power quality support, fraud detection and load/source shedding. These functions are a domain of the overall power automation, which is currently only loosely coupled to the meter domain.

In power automation a metering object description must be present. This should be consistent with the DLMS/COSEM standards. Currently that has not been realized. IEC SMB (Standardization Management Board) Smart Grid Strategic Group argues that the different domains (Energy Market, Transmission and Distribution, Distributed Energy Resources, Building, Industry, E-Mobility) need to define common interfaces. This is currently not supported by standards.

Smart Grid Strategic Group recommends IEC 61850 should be expanded to include the DLMS/COSEM objects. In their estimation this would require no extensions or changes in DLMS and would promote the coexistence of meter and smart grid application. Furthermore the TC 57 framework needs to be expanded to include metering data in any case. Basing that on DLMS/COSEM would pose the advantage of implementing a standard object description instead of proprietary metering protocol.

According SMB Smart Grid Strategic Group the different functions of automation, automated meter reading and communication systems must be brought together at the interface of the smart grid device (including meter and other AMI devices). A set of objects and profiles should be described and standardized in order to give guidelines for paths to interoperability of these domains. This task should be performed jointly by TC 8, TC 13 and TC 57. In order to enable an interface to building and home automation, they recommend, a liaison to ISO TC 205 and ISO/IEC JTC 1 should be sought. TC 57 has already developed a method to prove conformity to its standards through the means of UCA (Utility Communications Architecture) interoperability tests and conformance testing is available for DLMS/COSEM from DLMS UA. This would be a way to limit the often wide scope of standards to a set of interoperable functions, which can be supported by standards.

IEC 61850 and demand response and supply/demand sides

Demand response includes the mechanisms and incentives needed for utilities, power generators, power storage, energy market, energy retailers, industrial, building and residential customers, electricity installers/contractor to contribute to grid level optimization.

This includes (but is not limited to):

- Shaping energy load profiles over time by requesting changes in current use:
- Shaping the generation (bulk and DER) profiles depending on selected criteria (production constraints, emission regulation, energy price).
- Performing power network ancillary services when energy quality (voltage, frequency) criteria may not be reached or power reliability is at risk.

The first and most important step for industry is to understand where and how energy is being consumed or exchanged. Daily and seasonal variations have to be considered. It is more and more common to have on site an energy management system which ensures the availability of electricity and provides a first level of understanding of how the electrical

network is loaded (monitoring load consumption, switchboard load and spare capacities), which is the current power quality (monitoring harmonics, sags, …), which source is currently active, and possibly offers remote manual and/or automatic means to control the network and then increase the field staff efficiency, while improving the electricity availability. The energy management system can be stand-alone or can be part of the process automation system. This applies to industrial processes, electrical components linked to the processes and auxiliary equipment. In many cases, the same technology is used on the power utility supply side (substation automation technology) and demand side.

In order to facilitate energy management, all the equipment related to the process, to the electrical installation and to the auxiliary services should be able to communicate together. Because of many existing industrial processes, an important consideration is the ability to upgrade on-site energy systems to enable integration with smart grid signals such as dynamic pricing and curtailment demand response. Demand response is necessary for optimizing the balance of power supply and demand and the balance of reactive power supply and demand, and appears as one cornerstone of smart grid deployment. SGCG Report Programme of standardisation work for the Smart Grid notes: “The demand response mechanism is not considered yet to support network ancillary services. We recommend extending the IEC 61850 model (DER) and other DR information channels to support ancillary services participation”.

The normative definition of logical nodes for DER is necessary for new smart grid appliances because process devices have to be described in such logical nodes for information exchange. Therefore it is important that currently valid logical nodes in process protocols are not subject to change in the further standardisation process. Distributed generation and storage is becoming increasingly important. Similarly, the importance of demand response will grow in the future. Object models are important architectural cornerstones in today’s automation systems.

Current standards of communication in electrical distribution systems in Germany are IEC 60870-5-101 and -104. They are in use for HV/MV-substations. ZSDis/E.ON as DSOs support the development of IEC 61850 as a common future standard with focus on feed-in management and MV/LV-substation-automation. The DSOs’ needs have to be taken into account during standard development, otherwise complex and expensive solutions could result. The developments of parts of 61850 series offer the possibility to improve the network management. They may become useful for ancillary network services for medium voltage like voltage control and reactive power management.

A close cooperation with the “demand response” activities is needed. Here use cases must be defined in order to specify the scope and involvement of the different stakeholders. For example the contribution of smart appliances or building automation systems needs to be described in order to define their share in the overall systems. Regarding tariff information - On-site energy management systems should be able to spread tariff information down to the load. We recommend extending the IEC 61850 model (the most common backbone system for EMS) to support tariff related information.

As the exchange of metering data and tariff information is fundamental to the implementation of smart grids, ZSDis/E.ON as the DSO supports the efforts to harmonize the standards in this area. We agree that the further development of different and competing standards for the same purpose could lead to unnecessary costs and complexity.

8.5.2 IEC 61968 and IEC 61970

IEC 61968 and IEC 61970 standards provide information models of transmission, distribution systems and energy markets, as well as partial models of power generation, models known as the CIM (Common Information Model), structure and semantics for integrating a variety of back-office applications. IEC 61968 and IEC 61970 were identified as core standards for smart grids.

The CIM (Common Information Model, standardized in IEC 61968 and IEC 61970) defines a common language and data modelling with the object of simplifying the exchange of information between the participating systems and applications via direct interfaces. The CIM data model describes the electrical network, the connected electrical components, the additional elements and the data needed for network operation as well as the relations between these elements. The Unified Modelling Language (UML), a standardized, object-oriented method that is supported by various software tools, is used as the descriptive language. CIM is used primarily to define a common language for exchanging information via direct interfaces or an integration bus and for accessing data from various sources.

The CIM forms the basis for the definition of important standard interfaces to other IT systems. The working group in IEC TC 57 plays a leading role in the further development and international standardization of IEC 61970 and the CIM. Working group WG14 (IEC 61968 Standards) in the TC 57 is responsible for standardization of interfaces between systems, especially for the power distribution area. Standardization in the outstation area is defined in IEC 61850.

8.5.3 IEC 60870-5

IEC 60870-5 has been in use in some installations for switchgear automation. However when confronted with the full scope of IP network requirements, according to IEC SMB Smart Grid Strategic Group IEC 60870-5 cannot fully support the capability of IEC 61850 and therefore IEC 60870-5-104 is not an ideal candidate to meet future Smart Grid requirements, IEC 61850 seems to be better suited for this approach.

8.5.4 IEC 61851-1

IEC 61851-1 Annex A [116] describes a basic communication using a control pilot circuit and PWM modulation through a control pilot wire, which allows the charge spot to signal the available electric power to the EV

The “pulse width modulation” (PWM), is a technique used to “control” a power device. The method consists in driving the power device by means of a series of pulses at a constant frequency but with a variable cycle. The key factor to obtain such control is the duty cycle defined as:

$$duty\ cycle\ (d) = \frac{\tau}{T}\ \tau/T$$

where τ and T are the parameters represented in the next figure.

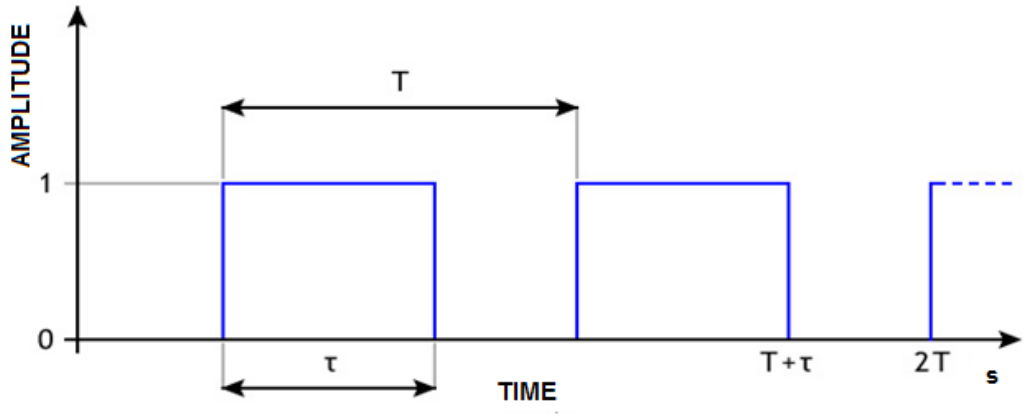


Figure 101. PWM duty cycle

In the case of the communication between the EV and the EVSE, the duty cycle is modified by varying the amplitude of the pulses (τ) in function of the EVSE available current information to be transmitted to the vehicle.

Annex A of IEC 61851 concerns all charging systems that ensure the pilot function with a pilot wire circuit with PWM modulation in order to define the available current level for mode 2 and mode 3 charging. This annex describes the functions and sequencing of events for this circuit, based on the recommended typical implementation circuit parameters. The parameters indicated have been chosen in order to ensure the interoperability of systems with those designed according to the standard SAE J1772 [22].

In the Annex, both a typical control pilot circuit and a simplified one are considered (see figures below). The simplified circuit can be used in special cases, when there is not a complete communication (PWM) on the vehicle side. It therefore shall not be used for vehicles drawing more than 16 A single phase (it shall not be used with 3-phase supply).

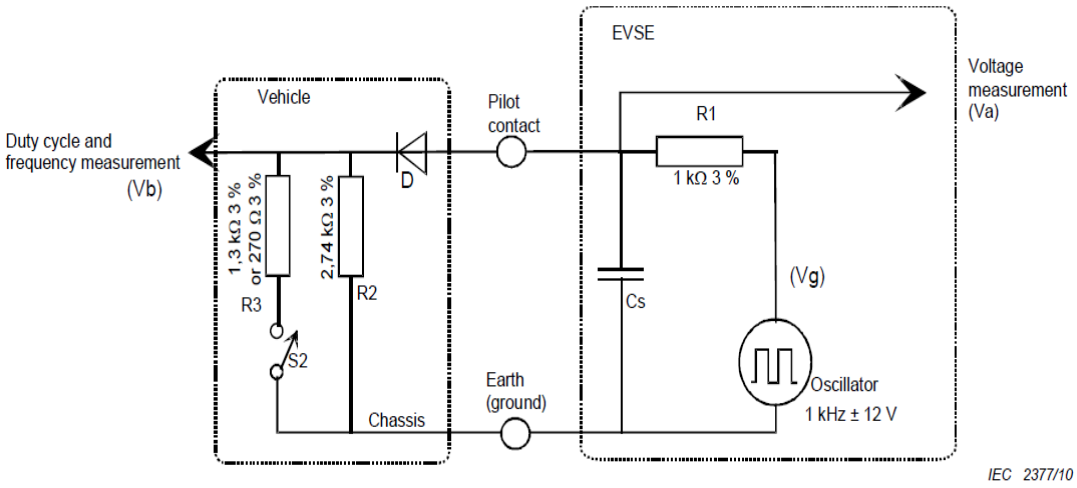


Figure 102. Typical control pilot circuit according to IEC 61851-1 Annex A [116]

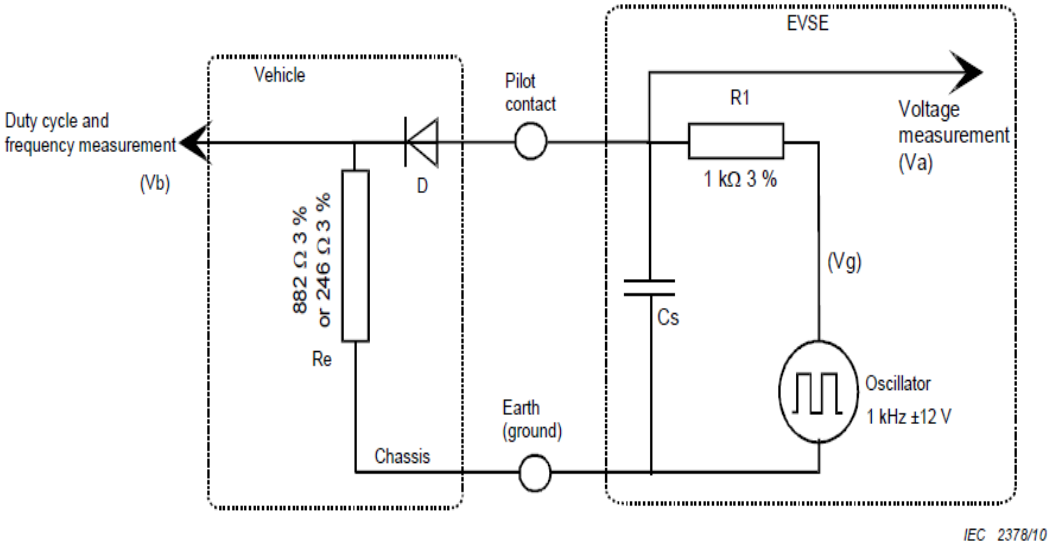


Figure 103. Simplified control pilot circuit according to IEC 61851-1 Annex A [116]

Once the vehicle is connected with the charging station, the EVSE can transmit current to the vehicle after the closing of switch “S2” and thus beginning to modulate in PWM.

The table below shows, the nominal duty cycle (in percentage) that the EVSE should provide the EV to inform about a defined current limit or to establish a digital communication through the pilot wire.

Available line current	Nominal duty cycle provided by EVSE (Tolerance ± 1 percentage point)
Digital communication will be used to control an off-board DC charger or communicate available line current for an on-board charger.	5 % Duty Cycle
Current from 6 A to 51 A:	(% duty cycle) = current[A] / 0,6 10 % ≤ duty cycle ≤ 85 %
Current from 51 A to 80 A:	(% duty cycle) = (current[A] / 2,5) + 64 85 % < duty cycle ≤ 96 %

Figure 104. Pilot duty cycle provided by the EVSE [116]

The related maximum current that can be drawn by the vehicle is reported in the following table.

Nominal duty cycle interpretation by vehicle	Maximum current to be drawn by vehicle
Duty cycle < 3 %	Charging not allowed
3 % ≤ duty cycle ≤ 7 %	Indicates that digital communication will be used to control an off-board DC charger or communicate available line current for an on-board charger. Digital communication may also be used with other duty cycles. Charging is not allowed without digital communication. 5 % duty cycle shall be used if the pilot function wire is used for digital communication
7 % < duty cycle < 8 %	Charging not allowed
8 % ≤ duty cycle < 10 %	6 A
10 % ≤ duty cycle ≤ 85 %	Available current = (% duty cycle) × 0,6 A
85 % < duty cycle ≤ 96 %	Available current = (% duty cycle - 64) × 2,5 A
96 % < duty cycle ≤ 97 %	80 A
Duty cycle > 97 %	charging not allowed
If the PWM signal is between 8 % and 97 %, the maximum current may not exceed the values indicated by the PWM even if the digital signal indicates a higher current.	

Figure 105. Maximum current to be drawn by the EV [116]

While 8 to 97% duty cycles indicate a maximum available current for charging, 3-7% duty cycle introduces high level digital communication, which can be performed according to ISO/IEC 15118 protocol (see next chapter).

The next figures illustrate a complete typical charging cycle controlled using PWM modulation. It has eleven sequential states, beginning from the cable connection of EV and EVSE (S2 closed) and ending with the complete charging. The states of the vehicle and the sequences of the charging process are described in the table below.

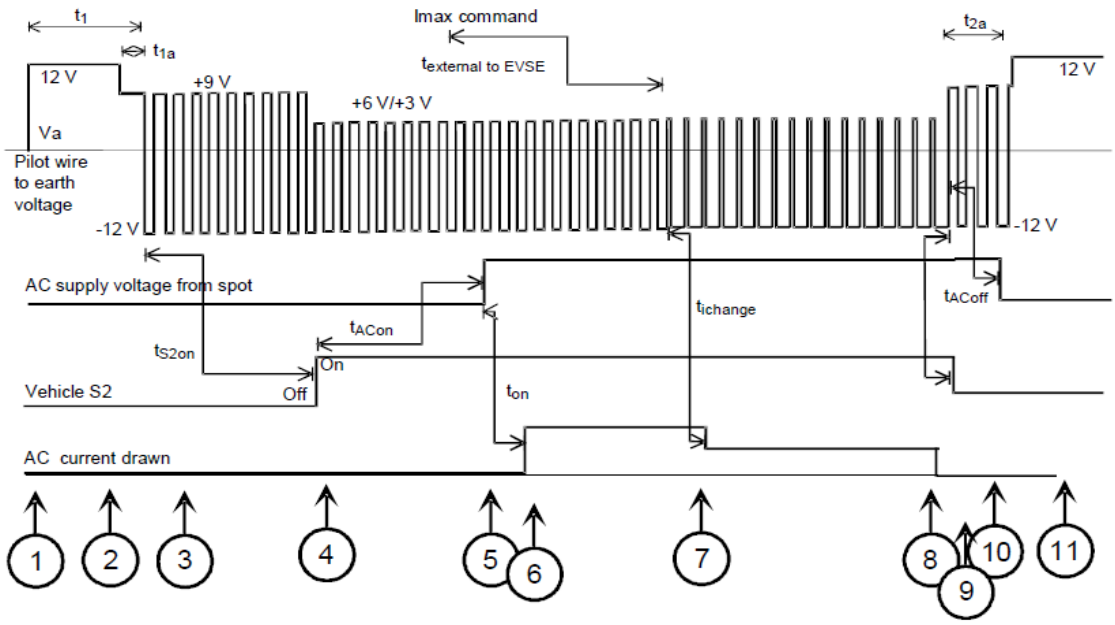


Figure 106. PWM Typical charging cycle under normal operating conditions [116]

	State	Conditions
1	A	Vehicle unconnected – the full generator voltage is measured by the EVSE at Va (see Figure A.1). The generator signal Vg is a +12 V DC voltage
2	B	The cable assembly is connected to the vehicle and to the EVSE. This condition is detected by the 9 V signal measured at Va. The voltage from the signal generator (Vg) may be either a steady state +12 V DC or a ±12 V, 1 kHz signal in conformity with Table A.1 if the EVSE is immediately available for the supply of energy.
3	B	The EVSE is now able to supply energy and indicated the available current to the vehicle by the duty cycle in conformity with Table A.5. The presence of the diode D (see Figure A.1) is detected by the – 12 V and gives added guarantee that the 9 V signal is a reliable indication of a vehicle connected.
4	B → C,D	S2 is closed by vehicle as a function of requirements to indicate that the vehicle can receive energy. There are no timing requirements for the closing of On.
5	C,D	EVSE closes circuit. The timing of switch closure may be subject other requirements (payment, data exchange). If state D is detected, the switch will close only if ventilation requirements are met.
6	C,D	Current drawn from the vehicle. The timing and current profile are determined by the vehicle. Current may not exceed that indicated by the duty cycle (Table A.5).
7	C,D	External demand for power reduction. Such a demand may originate from the grid or by manual setting on EVSE. The Vehicle adjusts the current demand to that indicated by the duty cycle.
8	C,D	End of charge, decided by the vehicle.
9	C,D →B	Vehicle asks for disconnect. This may be the result of the proximity contact being opened.
10	B	EVSE detects state B (created by opening of S2 on vehicle) and opens the contactor.
11	A	Complete removal of cable assembly from vehicle or EVSE is detected by the 12V signal.
NOTE	The EVSE should allow removal of the plug if the end of the charging session is ended by entering state A.	

Figure 107. Description of charging sequences for Figure 106 [116]

8.5.5 ISO/IEC 15118

The IEC 15118 standard series deals with the communication between an electric vehicle and a charge point (electric vehicle supply equipment) for the purpose of initializing and configuring the charge process of an EV. The currently published documents of the series are the following two:

- 15118-1: General information and use-case definition
- 15118-2: Network and application protocol requirements

Other documents are currently under development, and their complete list is the following:

- 15118-3: Physical and data link layer requirements
- 15118-4: Network and application protocol conformance test
- 15118-5: Physical layer and data link layer conformance test
- 15118-6: General information and use-case definition for wireless communication
- 15118-7: Network and application protocol requirements for wireless communication
- 15118-8: Physical layer and data link layer requirements for wireless communication

Inside the standard, the electric vehicle and the charge point are identified as 'primary actors'. Other systems which may be indirectly impacted by the standard are identified as 'secondary actors'. Both primary actors and secondary actors are illustrated in the following figure, extracted from the 15118-1 document.

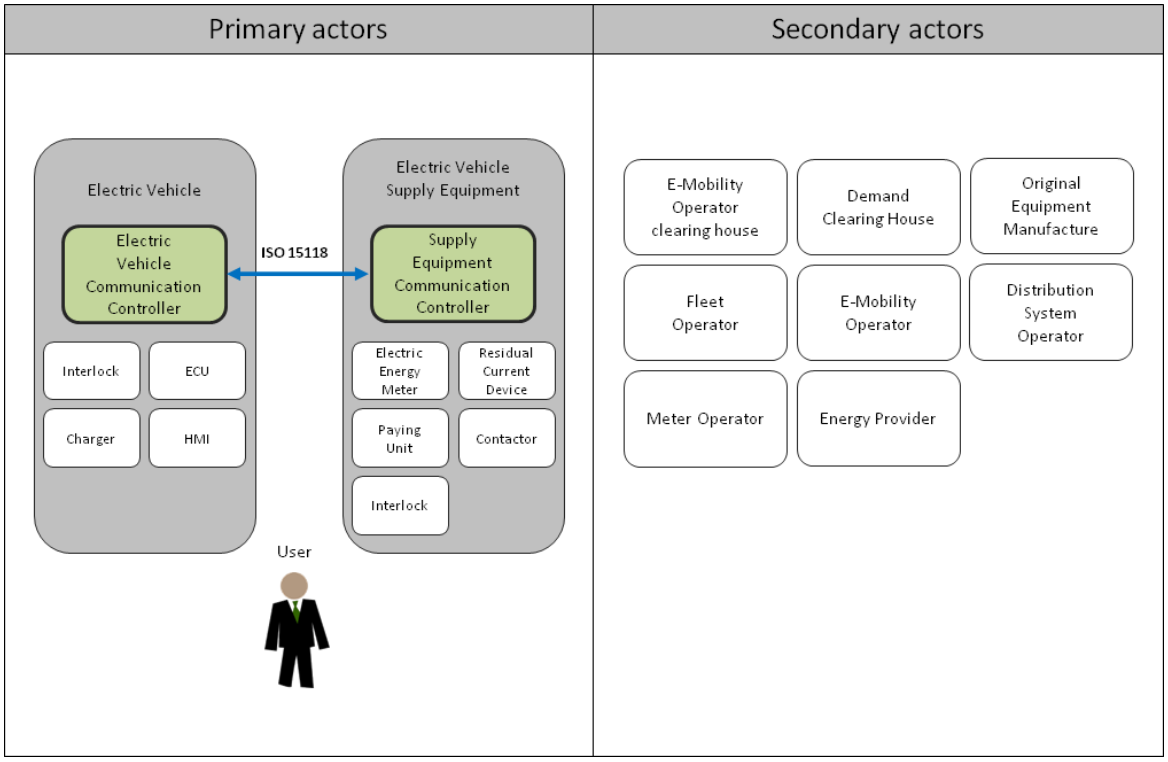


Figure 108. ISO/IEC 15118 Actors

Since the parts 3-8 of the standard are still under development, only parts 1 and 2 will be taken into account for this summary: these two parts are also the most interesting for a

high level understanding of the offered functionalities, since parts 3-8 are mostly focused on very specific issues such as physical layer requirements and conformance tests.

IEC 15118-1 defines all the **use cases** relevant to the standard, i.e. all the functionalities which are expected to be implemented by conformant systems, grouped into eight categories (called function groups in the standard):

- **Start of the charging process**: initiation of the process between vehicle and EVSE after the physical plug-In of the vehicle. It sets the basis for the ongoing charging process e.g. availability of PWM, high-level communication etc.
- **Communication setup**: establishes the association and relevant connection between EVCC and SECC.
- **Certificate Handling**: everything related to certificates.
- **Identification, Authentication and Authorization**: methods for identification, authentication and authorization.
- **Target setting and charging scheduling**: information needed from the EV as well as from SECC and the secondary actor to start the charging process and charging.
- **Charging controlling and re-scheduling**: elements needed during the charging process.
- **Value-added services**: elements not directly needed for pure charging of electric vehicles.
- **End-of-charging process**: Describes the trigger for signalling the end of the charging process.

In the first part, all the use cases are expressed in an abstract way, i.e. there is no protocol specification, just a list of functionalities which must be supported by the standard. The actual application protocol and messages which must be used to implement these functions are defined in the second part of the standard (15118-2). In turn, low level details regarding the physical transmission of these messages are discussed in part 3 (and part 8 for wireless communication); in fact, part 2 simply requires the underlying network infrastructure to support the transmission of IP packets.

Moreover, the standard is designed to be compatible with 61851, so that the various use cases take into account the possibility that the electric vehicle or the charging point (or both) have no support for the protocol defined by 15118 (called *high level communication protocol* inside the standard's document).

Each **function group** contains one or more **elementary use cases**, describing a simple interaction between the electric vehicle and the charging point; the complete list of elementary use cases identified by 15118-1, which together form the complete set of **functionalities** which must be supported by the protocol, is the following:

- **A - Start of the charging process**
  - A1 - Start of charging process with forced high-level communication
    - Objectives: establishing of high- level communication.
    - Description: high-level communication required by EVSE, PWM signal (according to IEC 61851-1) at 5 % duty cycle in order to force high-level communication and mode 3 charging. EVSE will not provide power to EVs that do not support high-level communication, unless in that case an authorization by any other means took place.

- A2 - Start of charging process with concurrent IEC61851-1 and high-level communication
  - Objectives: establish high-level communication concurrently with IEC 61851-1 mode 3 charging.
  - Description: high-level communication optional, EVSE will provide power even to those EVs that do not support high-level communication. This use case covers the initial PWM signalling (IEC 61851-1 mode 3) from the EVSE and high-level communication working concurrently."

- **B - Communication setup**
  - B1 - EVCC/SECC communication setup
    - Objectives: the goal of this use case element is to establish a communication link between EVCC and SECC and correct association.
    - Description: there is no information exchange between the EVCC and the SECC at application layer, the actors are: SECC and EVCC.
- **C - Certificate Handling**
  - C1 - Certificate update
    - Objectives: replace the expired certificate in the EV with a new and valid certificate from the secondary actor.
    - Description: this use case covers the update of an expired certificate in the EV. Therefore, the EVCC is initiating a certificate update process using the established high-level communication with the SECC to retrieve a new certificate from the issuing secondary actor.
  - C2 - Certificate installation
    - Objectives: installation of a new certificate from the secondary actor in the EV.
    - Description: this use case covers the installation of a certificate (Contract Certificate) into the EV if no such certificate is available yet / it has expired / is invalid. Therefore, the EVCC is initiating a certificate installation process using the established high-level communication with the SECC to retrieve a certificate from the issuing secondary actor. The EV is identified by using a certificate (Bootstrap Certificate) that was installed by the OEM earlier (e.g. at EV production).
- **D - Identification, Authentication and Authorization**

  Identification and authentication cases: Depending on the EVSE infrastructure and the capabilities of the EV, the methods of identifying a user differs. For ISO/IEC 15118 only the cases are normative with high-level communication between EVCC and the SECC. Other alternatives for identification are listed in the informative section.

  Authorisation case: Depending on the EVSE design, many authorisation methods are thinkable in the future. However, all authorization methods could be categorised by means of authorisation location and authentication. Authorisation covers all methods for services rendered to the client. It includes the payment for electricity supplied to the vehicle and the authorisation to receive a requested value-added

service. Payment for electricity concerns relatively small amounts, other services (e.g. car rental) may concern larger amounts and may require supplementary security.

- D1 - Authentication from EV with local Authorisation:
  - Objectives: Authenticate and authorise the validity of the contract by using the ISO/IEC 15118-2 message set.
  - Description: This use case covers the authentication process from the EV. The identification should be made with an ID as stipulated in ISO/IEC 15118-2.
- D2 - Authentication from EV with Authorisation from secondary actors:
  - Objectives: Authenticate and authorise the validity of the contract with a validation from a secondary actor by using the ISO/IEC 15118-2 message set.
  - Description: This use case covers the authentication process from the EV. The identification should be made with an ID as stipulated in ISO/IEC 15118-2
- D3 - Identification at EVSE
  - Objectives: Identification of the user at EVSE.
  - Description: User identifies himself at the EVSE by using one of the identification methods offered.
- D4 - Identification at the EVSE with validation from the secondary actor
  - Objectives: Identification with validation from the secondary actor.
  - Description: This use case covers the process of how identification should be validated by a secondary actor. User identifies himself at the EVSE by using one of the identification methods offered.

- **E - Target setting and charging scheduling**
  - E1 - AC charging with load levelling based on high-level communication
    - Objectives: This use case covers only charging within local charging infrastructures Dynamically Adjustment of the maximum AC current to be drawn by the EV within the limits of the local installation.
    - Description: The SECC and EVCC exchange information about the AC current limits using high level communication. The SECC communicates the maximum power that can be drawn from the outlet, in order to protect the EVSE, to the EVCC.
  - E2 - Optimised charging with scheduling from the secondary actor
    - Objectives: Dynamic adjustment of the maximum power to be drawn by the EV. Prognosis of the power drawn by the EV which can be dynamically adjusted.
    - Description: This use case covers the AC charging process with information about local installation, grid schedule and sales tariff table. With this, the EVSE can dynamically react to changes in the supply chain to reduce peak demand or oversupply situations. Additionally, the behaviour of the vehicle while charging becomes transparent to secondary actors in order to enhance electricity supply scheduling.
  - E3 - Optimised charging with scheduling at EV
    - Objectives: Dynamically adjustment of the maximum power to be drawn by the EV. Prognosis of the power drawn by the EV which can dynamically adjusted.

        - Description: This use case covers the AC charging process with information about local installation, grid schedule and sales tariff table. With this the EV can react on changes in the supply chain to reduce peak demand or oversupply situations. Additionally the behaviour of the vehicle while charging becomes transparent to secondary actors in order to enhance electricity supply scheduling. The secondary actor needs to provide a grid schedule and sales tariff table to the SECC. The SECC forwards this information, together with the local limitations, to the EVCC. It is necessary that the EVCC, SECC and secondary actor each have the possibility to trigger a re-scheduling of the charging profile.
    - E4 - DC charging with load levelling based on high-level communication
        - Objectives: Charging without considering complex grid situations and secondary actors. Dynamic adjustment of the max. DC power to be drawn by the EV within the limits of the local installation.
        - Description: The EVSE and EV will exchange information about the DC power limits using high-level communication. The EVSE will communicate the max. DC power that can be drawn from the outlet in order to protect the supply equipment to the EV. The EV and the EVSE exchange control information for the battery management system.
    - E5 - Resume to authorised charging schedule
        - Objectives: Restart sleeping charging schedule.
        - Description: This use case covers the resume process to once authorised and sleeping charging schedule.
- **F - Charging controlling and re-scheduling**
    - F0 - Charging loop
        - Objectives: Continue charging process until success conditions reached and enable billing of transferred energy.
        - Description: This use case covers the basic loop charging. The following information needs to be exchanged between EV, EVCC EVSE, and SECC.
    - F1 - Charging loop with metering information exchange
        - Objectives: Continue charging process until success conditions reached and enable billing of transferred energy.
        - Description: This use case covers the basic loop charging with meter readout. For reliable billing of transferred energy, the utility must be able to prove that a specific amount of measured energy was delivered to a specific EV / customer. It is therefore mandatory that the transferred energy is confirmed by the EV/ customer. With respect to the communication between EVCC and SECC, one possibility is that the vehicle signs the meter information from the SECC to confirm the reception of this meter. The vehicle may perform a plausibility check between the EVSE measured energy amount and the received energy amount to validate if there is an unexpected high-energy loss during the charging process.
    - F2 - Charging loop with interrupt from the SECC

        - Objectives: Continue charging process until the SECC interrupts the charging loop.
        - Description: The EVCC is the 'client' and always requests information from the SECC. If an SECC wants to interrupt the charging loop, for example with an updated charging schedule or new set point for the load levelling, then this use case will describe the process.
    - F3 - Charging loop with interrupt from the EVCC or user
        - Objectives: Possibility for the EVCC or user to interrupt the charging loop.
        - Description: EVCC or user interrupts charging process when e.g. charging schedule changes or unpredictable event in the EV occurs or user returns and wants to leave.
    - F4 - Reactive power compensation
        - Objectives: EV supports the EVSE in reducing reactive power in the grid.
        - Description: This use case element covers the exchange of information regarding the possibility of reactive power compensation from the EV side and the demanded reactive power compensation from the EVSE or grid side.
    - F5 - Vehicle to grid support
        - Objectives: EV can supply energy back to the grid.
        - Description: This use case element covers the exchange of information regarding the principle and actual possibility of supporting vehicle to grid energy flow. Therefore, the EV needs the possibility to indicate that it can technically support vehicle to grid energy flow. Additionally, it needs the possibility to provide information as to how much energy is available for vehicle to grid operation, and with which power this operation can be supported.
- **G - Value-added services**
    - G1 - Value-added services
        - Objectives: Value-added service (VAS) information exchange between the EVCC and SECC.
        - Description: Optional services that may connect to the local network domain (EVSE) or the internet using optional protocols. Protocols on different communication layers may be used e.g. DHCP, HTTP, SOAP, and HTML.
    - G2 - Charging details
        - Objectives: Information supply of current charging process to the vehicle user or secondary actor.
        - Description: This use case covers the exchange of information regarding the current charging process to the SECC. Parameters like battery status and state of charging could be provided for the SECC. The SECC or secondary actor, aware of the status of its charging process, delivers information to the vehicle user.
- **H - End-of-charging process**
    - H1 - End of charging process

- Objectives: Closing down the charging process in a safe and secure way whilst exchanging all relevant information required for subsequent procedures.
- Description: This use case covers the basic ending charging process, with primary actors: EV, EVCC EVSE, SECC, and User.

The following figure sums up the **use case approach** in this standard [71].

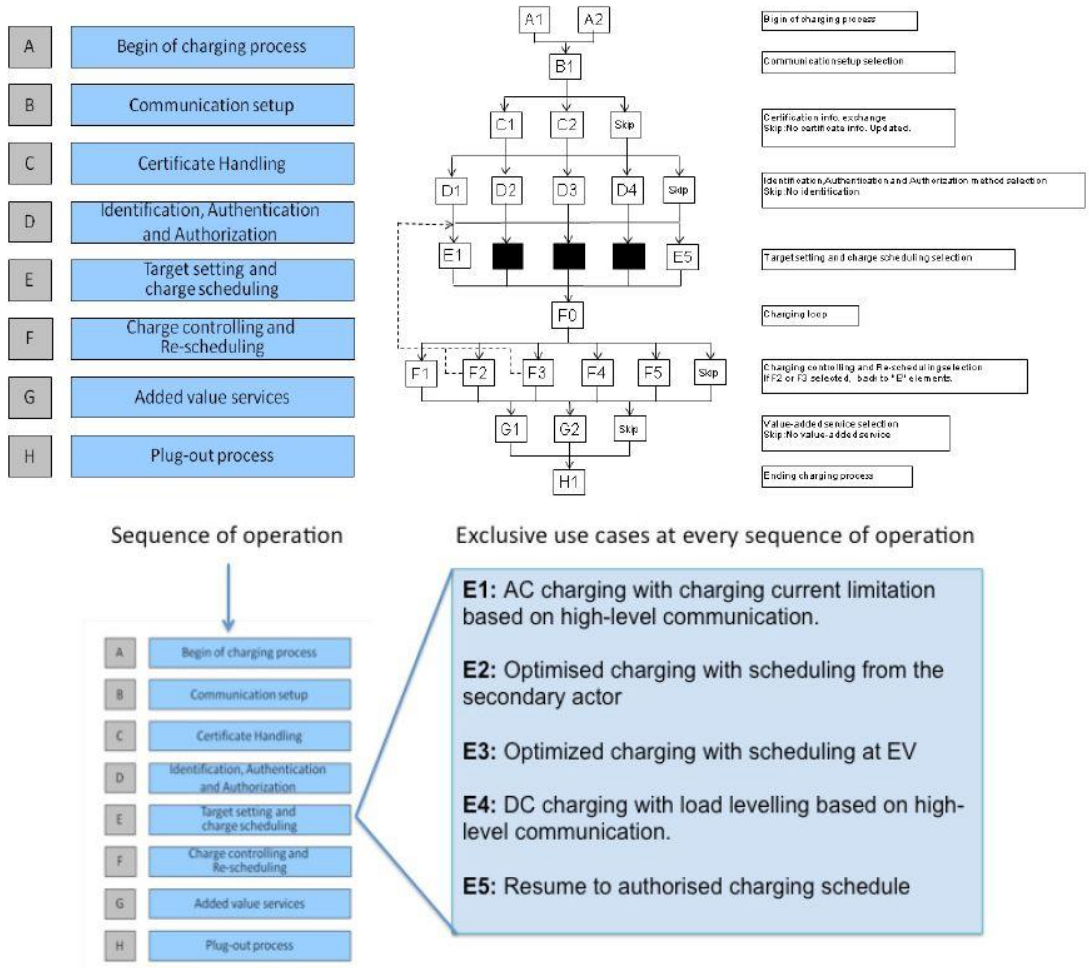


Figure 109. ISO/IEC 15118 - Use cases summary [71]

According to the Smart Charging Working Group, new cases, even out of the scope of this standard should be further explored:

- The vehicle is charged in the public or private domain and maximum power may be limited by contract with the DSO.
- The charging system is part of a complex system which will probably include an intermediate energy controller and the corresponding business case.
- Management of the charging infrastructure and data flow.
- The global influence of charging behaviour (aggregation, statistical and provisional).
- The charging session schedule must be established based on the client and system needs in regards to data privacy: journey to be accomplished, information related to scheduling and timing constraints, desired price, etc.

- The capacity and functionality of the complete system (vehicle, charge spot, local installation, grid capacity, etc.).
- Charging spot accessibility and capability.
- Geographical location of charging spots related to the journey.

Some **examples of basic information** that is likely to influence future charging sessions are provided by the same reference:

- Client request for charging:
  - Time constraints.
  - Price constraints.
  - Convenience (less than x km from my way, in a certain period of the day).
  - Charging target (according to km to cover, % of battery capacity, CO_2 emissions, energy prices).
  - Roaming information (preferred options).
  - Pre-booking of a public charging spot.
  - Spots availability along my journey.
- Information required at the charging spot to optimize energy:
  - Remaining charge of the battery.
  - Time to next usage.
  - Required energy to next usage.
  - Time and money required to charge up to a certain level.
  - Power available at charge spot, power level accepted by the vehicle.
  - Re-negotiation of power delivery accepted or not by the EV.
  - Extra services required like vehicle pre-heating or cooling, map or video download.
  - Index of interruptible charging services.
- Billing information:
  - Identification of client.
  - Smart Charging behaviours.
  - Smart metering.
  - Consumption profile.
  - Environmental information.
  - Price information.
- Other types of information, which are difficult to handle with today's systems:
  - Impact of renewable energy sources (fluctuation, forecast, price)
  - Impact of V2G, V2H, V2Neighbourhood

Diving into the **messages** defined in part 2 of the standard provides information about the data exchanged in the charging process, which results are quite interesting. They are based on a request/response pair and an example of the messages that could be exchanged under ISO/IEC protocol is shown in the next figure.

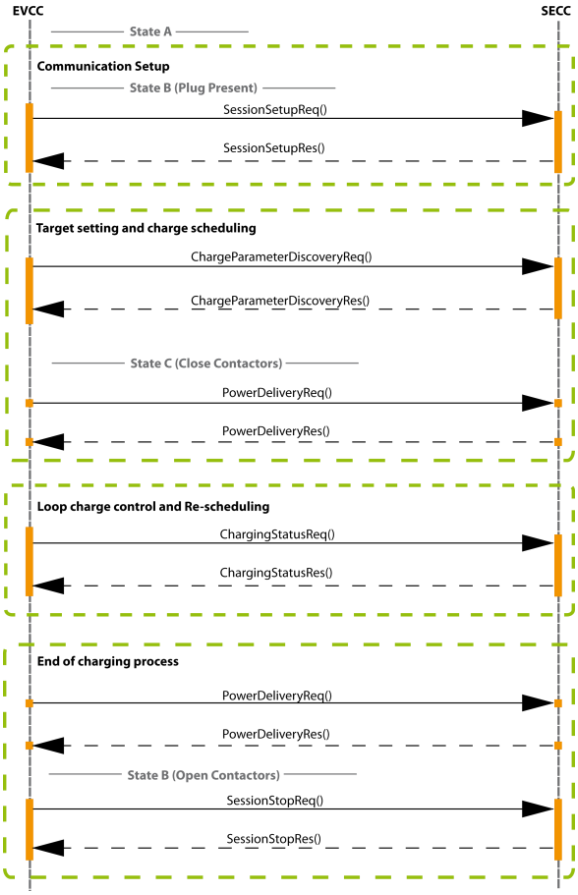


Figure 110. ISO/IEC 15118 Smart charge message exchange example

After connection has been established between EV and CP the V2G communication session is established on application layer (**Session Setup**). The following data is exchanged by means of a message pair:

- **Session Setup Request:**
  - EVCC ID
- **Session Setup Response**: the CP notifies the EV whether establishing a new session or joining a previous communication session was successful or not.
  - Response Code (OK, Failed)
  - EVSE ID
  - EVSE Timestamp (optional)

After being authorized for charging, the EVCC and the SECC negotiate the charging parameters with the **Charge Parameter Discovery** message pair. Before the onset of the energy supply, the EV will negotiate with the EVSP and other secondary actors indirectly, to fit the predicted available electric power. The available power may change once the charging has started, due to sudden lack of power source, increase of demand, etc. A new negotiation must be allowed in this case. The following message pair is exchanged in the process:

- **Charge Parameter Discovery Request**: the EV provides its charging parameters to the EVSE.

- MaxEntriesSAScheduleTuple (Optional: Indicates the maximal number of entries in the SAScheduleTuple (applies for both Pmax and Tariff). The EVSE can transmit up to the maximum number of entries defined in the parameter)
- RequestedEnergyTransferMode (Selected energy transfer mode for charging that is requested by the EVCC)
- AC_EVChargeParameter (This element is used by the EVCC for initiating the target setting process for AC charging) or DC_EVChargeParameter (This element is used by the EVCC for initiating the target setting process for DC charging)

- **Charge Parameter Discovery Response**: the message the CP provides applicable charge parameters from the grids perspective.
  - EVSE processing (finished, ongoing)
  - Response Code (OK, Failed)
  - Secondary Actor (SA) schedule list
    - SA schedule tuple:
      - SA schedule tuple identifier
      - Maximum power schedule
        - Maximum power schedule identifier
        - List of max. power entry elements
          - Valid time interval
            - Duration (optional)
            - Start (seconds from now)
          - Maximum power to be drawn
      - Sales tariff
        - Sales tariff identifier
        - Sales tariff description (optional)
        - Maximum level price steps
        - Sales tariff entry
          - Valid time interval
            - Duration (optional)
            - Start (seconds from now)
          - Energy price
          - Other costs (optional)
            - Cost (optional)
              - Amount
              - Multiplier (optional)
              - Cost type (relative , renewable generation, CO_2 emission)
            - Lowest level of consumption
        - Attribute: IDREF (index reference)
  - AC EVSE (CP) charge parameters or DC EVSE (CP) charge parameters

The **power delivery** message exchange marks the point in time when the EV can start to charge its batteries:

- **Power Deliver Request**: the EV requests the CP to switch power on and transmits the charging identification mode it will follow during the charging process.

- ChargeProgress (This message element is used to request the EVSE to fulfil all conditions that the energy transfer can start as soon as the EV on-board system begins to retrieve energy without any further action to be taken (i.e. the EVSE is requested to close its contactors successfully). If ChargeProgress is equal to 'Start' the EVSE is requested to prepare the energy flow for an immediate start, if ChargeProgress is equal to 'Stop' the EVSE is requested to stop the energy flow , if ChargeProgress is equal to 'Renegotiate' the energy flow is neither stopped nor started, instead the renegotiation mechanisms defined in this standard apply.
- SAScheduleTupleID (Unique identifier within a charging session for a SAScheduleTuple element. An SAID remains a unique identifier for one schedule throughout a charging session).
- Charging profile:
  - Secondary Actor (SA) schedule tuple identifier
  - Profile entry:
    - Start (seconds from now)
    - Maximum power within the current entry
- DC_EVPowerDeliveryParameter (Optional: This element is used by the EVCC for transmitting the parameters for power delivery).

- **Power Delivery Response:** the CP sends the message including if the power is available.
  - Response Code (OK, Failed)
  - AC EVSE status or DC EVSE status

The **Charging Status** provides sanity checks on the meter readings provided by the EVSE. On the basis of the iteratively exchanged charging status messages the EV has means to check and validate the power drawn from the EVSE:

- **Charging Status Request**
- **Charging Status Response:** After receiving the Charging Status Request from the EV, the CP sends the Charging Status Response. It provides the current meter readings from the smart meter installed in the EVSE.
  - Response code (OK, Failed)
  - EVSE ID
  - Secondary Actor schedule tuple id (optional)
  - EVSE maximum current (optional)
  - Meter information:
    - Meter ID
    - Meter reading (optional) (Multiplier, unit – optional -, value)
    - Signature of the meter reading (optional)
    - Meter status (optional)
    - Timestamp of the CP (optional)
  - Receipt message required (true, false)
  - AC EVSE Status:
    - Power switch closed or not
    - Error detected at the RCD or not
    - Maximum reaction delay to EVSE notification
    - CP notification (none, stop charging, renegotiation)

The **Session Stop** message pair shall be used for terminating a V2G communication session initiated by preceding SessionSetupReq message.

The following scheme shows the exchanged data by this message pair:

- **Session Stop Request**: it indicates the EVCC intention to either pause or terminate a communication session.
- **Session Stop Response:** After receiving the Session Stop Request of the EV the CP sends the Session Stop Response informing if the process was successful.
    - Response code (OK, Failed)

Regarding the **protocol stack** used by IEC 15118, the reference documents are 15118-3 and 15118-8 for the physical and data link layer requirements (these documents are still under development, however) and 15118-2 for the upper OSI layers, as shown in the next figure. In short, the protocol is based on the exchange, between the electric vehicle and the charge point, of a set of XML messages. These XML messages are encoded and encapsulated by the lower OSI layer protocols shown in the figure, and then physically transmitted.

More in detail, the V2GTP protocol is a very simple framing protocol used to encapsulate upper layer messages; it consists of an 8 bytes header containing protocol version information, payload type and payload length. The presentation layer is based on EXI (Efficient XML Interchange), which is a W3C standard for a binary representation of XML streams. The application layer defines a set of XML payloads and message flows for the purpose of initializing and configuring the charge process of an EV, as well as a protocol called SDP (SECC Discover Protocol) that an EVCC can use to get the IP address and port number of the SECC. The XML payloads and message flows are required to support all the 15118-1 use cases. The transport and network layers use the standard TCP/IP protocols, so that they are not described into the 15118 standard itself.

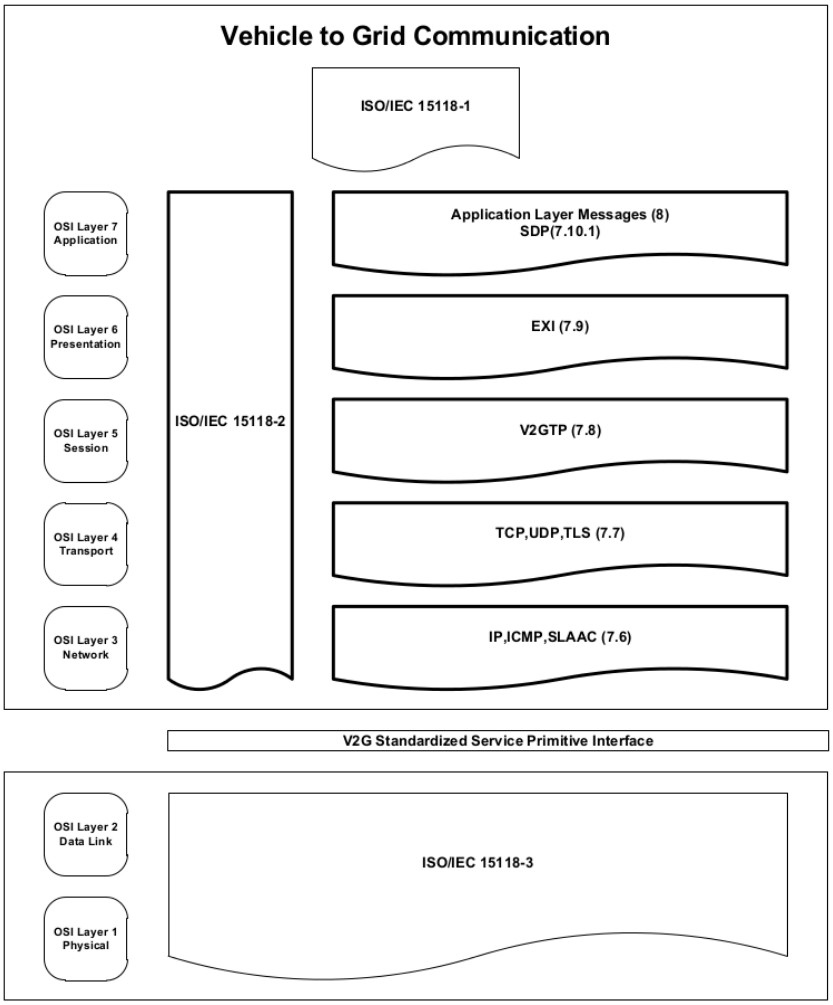


Figure 111. ISO/IEC 15118 layers

8.5.6 OCPP

The OCPP standard is currently developed by the Open Charge Alliance (http://www.openchargealliance.org), a consortium whose founding members are the E-laad foundation (Netherlands), Greenlots (North America), and ESB (Ireland). The scope of the protocol is the definition of the interface between Charge Points and a Central System, as shown in the following figure.

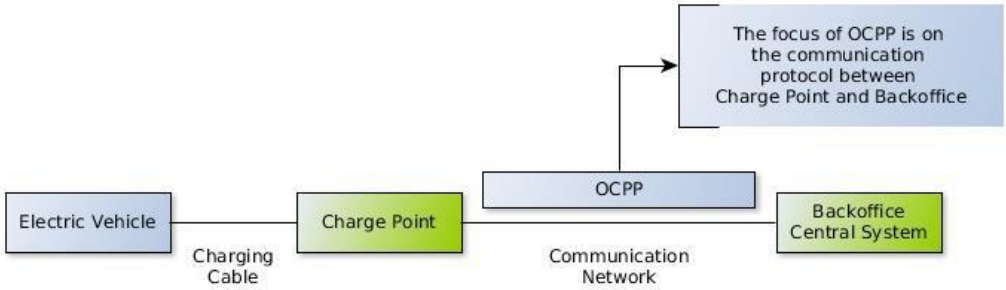


Figure 112. Scope of OCPP [118]

As specified in the standard, the Central System is a generic term identifying a "Centralized system that manages any number of charge points remotely". This simple architecture also allows for intermediate gateways, like a local controller which can aggregate a certain number of Charge Points: this will be illustrated in relation to Smart Charging services.

While the scope of the OCPP until version 1.5 was quite limited and dedicated to general purpose operations, version 2.0 [118] adds completely new services, related to pricing, Smart Charging and a device model for event and status reporting.

The **general services**, already present in OCPP 1.5 (even if in version 2.0 they were partially updated or renamed) are related to low-level management of the charge points. In particular, the list of operations that can be initiated by a charge point towards the Central System are the following:

- **Authorize**: before the owner of an electric vehicle can start or stop charging, the Charge Point needs to be able to authorize the operation. Only after authorisation will the Charge Point unlock the connector.
- **Boot Notification**: after start-up a Charge Point sends a notification to the Central System with information about its configuration (e.g. version, vendor, etc.). The Central System will only accept Charge Points that are registered with the Central System.
- **Data Transfer**: if a Charge Point needs to send information to the Central System for a function not supported by OCPP, it shall use the DataTransfer operation.
- **Diagnostics Status Notification**: Charge Point sends a notification to inform the Central System when a diagnostics upload has finished.
- **Firmware Status Notification**: a Charge Point sends notifications to inform the Central System about the progress of the firmware update.
- **Heartbeat**: to let the Central System know that a Charge Point is still connected, a Charge Point sends a heartbeat after a configurable time interval.
- **Meter Values**: a Charge Point may sample the electricity meter or other sensor/transducer hardware to provide extra information about its meter values.
- **Transaction Started**: the Charge Point informs the Central System about the start of a charging transaction.
- **Transaction Stopped**: the Charge Point informs the Central System when a transaction is stopped.

There is also a set of operations which can be initiated by the Central System towards charge points:

- **Cancel Firmware Update**: if a firmware update request has been previously sent to a Charge Point and has not been fully processed, the Central System can request a Charge Point to cancel a firmware update.
- **Cancel Reservation**: to cancel a reservation.
- **Change Availability**: Central System can request a Charge Point to change its availability. A Charge Point is considered available ("operative") when it is charging or ready for charging. A Charge Point is considered unavailable when it does not allow any charging.
- **Change Configuration**: Central System can request a Charge Point to change configuration parameters.
- **Clear Cache**: Central System can request a Charge Point to clear its cache. For instance a Charge Point may cache previously authorized cards.
- **Data Transfer**: if the Central System needs to send information to a Charge Point for a function not supported by OCPP, it shall use the DataTransfer operation.
- **Get Configuration**: to retrieve the value of configuration settings.
- **Get Diagnostics**: Central System can request a Charge Point for diagnostic information.
- **Get Local List Version**: in order to support synchronisation of the local authorisation list, Central System can request a Charge Point for the version number of the local authorisation list.
- **Request Start Transaction**: Central System can request a Charge Point to start a transaction.
- **Request Stop Transaction**: Central System can request a Charge Point to stop a transaction.
- **Reserve Now**: Central System can issue a Reserve Now command to a Charge Point to reserve a EVSE for use by a specific id-tag. This can be a specific EVSE or any EVSE on the Charge Point.
- **Reset**: for requesting a Charge Point to reset itself.
- **Send Local List**: Central System can send a local authorisation list that a Charge Point can use for authorisation of id-tags.
- **Unlock Connector**: Central System can unlock a connector of a Charge Point.
- **Update Firmware**: Central System can notify a Charge Point that it needs to update its firmware.

From a Charge Point perspective, the **pricing service** is quite simple, since all the most complicated issues, related for example to variable rates or peak/off-peak hours are handled by the Central System, in a way that this remains outside of the scope of the OCPP standard. The Charge Point just receives a set of pricing schemes from the Central system, like the two shown in the following figure, consisting in an energy tariff and a parking tariff.

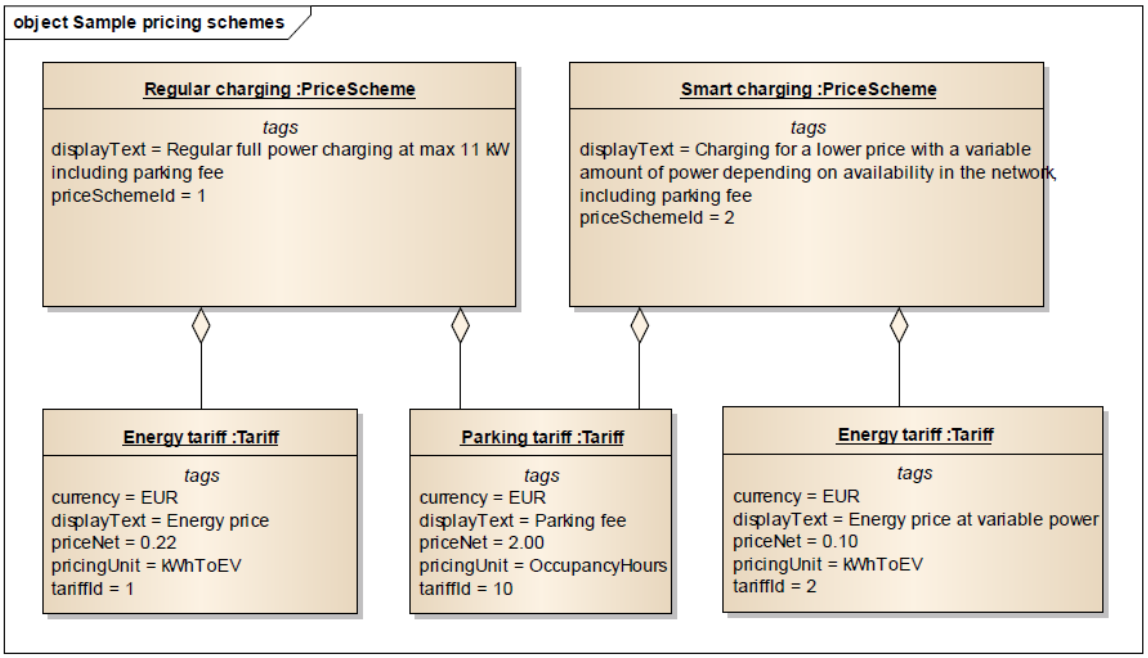


Figure 113. OCPP pricing schemes [118]

The Charge Point can present pricing schemes to the user and let him select the preferred one. Real time calculation of the running cost of the charging can be performed by the Charge Point for simple schemes, while for complex schemes it is always performed by the Central System and communicated to the Charge Point. It is also possible to implement user-specific pricing schemes, which are communicated by the Central System to the Charging Point after the authorization procedure.

The implementation of **Smart Charging** functionalities is based on the definition of 'charging profiles', which consists of a charging schedule (basically a list of time intervals and maximum power), and some values to specify the time period and recurrence of the schedule. Optionally, the profile can provide tariff information, for example to differentiate between peak and off-peak hours. The actual implementation logic depends on two factors:

- The presence of a local controller, which acts as a 'gateway' between the Central System and a certain number of Charging Points.
- The available communication methods between Charging Points and Electric Vehicles: in particular, OCPP considers the mode 3 PWM communication and ISO/IEC 15118 communication.

The local controller may receive an overall capacity profile from the Central System or use a preconfigured value. The actual algorithm used to 'split' the overall profile towards the different Charging Points is outside of the scope of the standard.

In case of mode 3 PWM communication between the Charging Points and the vehicles, the overall sequence diagram is shown in the following figure.

The basic explanation of the diagram, as reported in the OCPP standard document, can be found in Appendix III.

OCPP uses a rather simple **device model**, which can be used for event and status reporting. All of the monitoring, state and event reporting and configuration management information is communicated from the Charge Point to the Central System using a common *Notice* structure, whose structure is shown in the following figure.

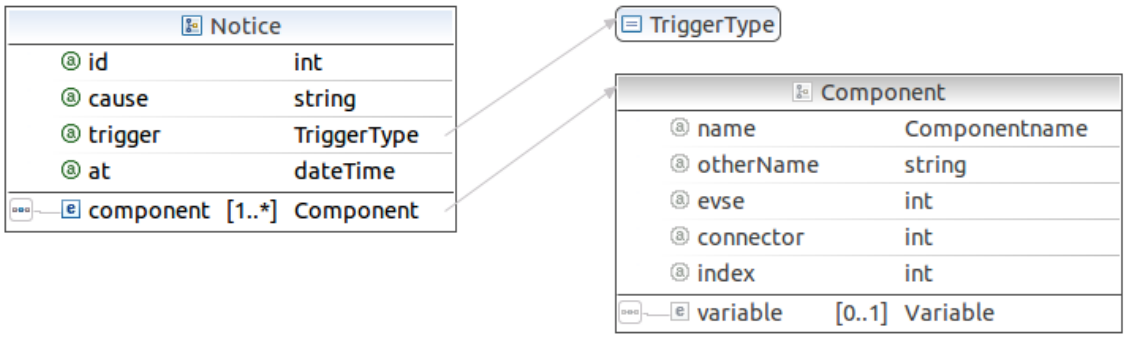


Figure 114. OCPP device model - Notice and Component

In particular, the *Component* structure represents an entity, hardware or software, involved in the event. Examples of Components are RFID reader, energy meter, firmware, etc. The OCPP document defines an enumeration of possible Component names to be used. Each Component can contain a set of Variables to describe its state (the XSD schema actually allows for one variable only, but this seems in contrast with the standard document description).

For general asynchronous events the OCPP protocol uses a dedicated message called *Notifications*, containing a set of Notices. Some events may be related to transactions, for example to the ending of a charging session: in this case the TransactionStopped message contains a Notifications element that can report relevant events that occurred during the charging session. Some other events may be related to monitoring, which in turn can be triggered by three different mechanisms:

- Alerting: alert and Critical Monitoring.
- Delta Value Change Monitoring (comprising the special case of Boolean State Monitoring).
- Periodic Monitoring.

The monitoring configuration can be remotely configured by the Central System using a dedicated service (SetMonitoring). Also, the operative configuration of each Charge Point can be modified by the Central System, for example to enable/disable particular functionality (e.g. Local Pricing).

8.5.7 OCHP

The OCHP protocol (Open Clearing House Protocol) can be used to implement a software platform called Clearing House, whose purpose is to allow the exchange of certain market data between the following actors: the Electric Vehicle Service Provider (EVSP), the Electric Vehicle Supply Equipment Operator (EVSE Operator) and the Navigation Service Provider (NSP). In turn, the final goal of these data exchanges is to allow Electric Vehicle Users (EV Users) to easily charge their Electrical Vehicle on every charging station of

different EVSE operators (roaming). The interfaces taken into account by the standard are shown in the following figure [119].

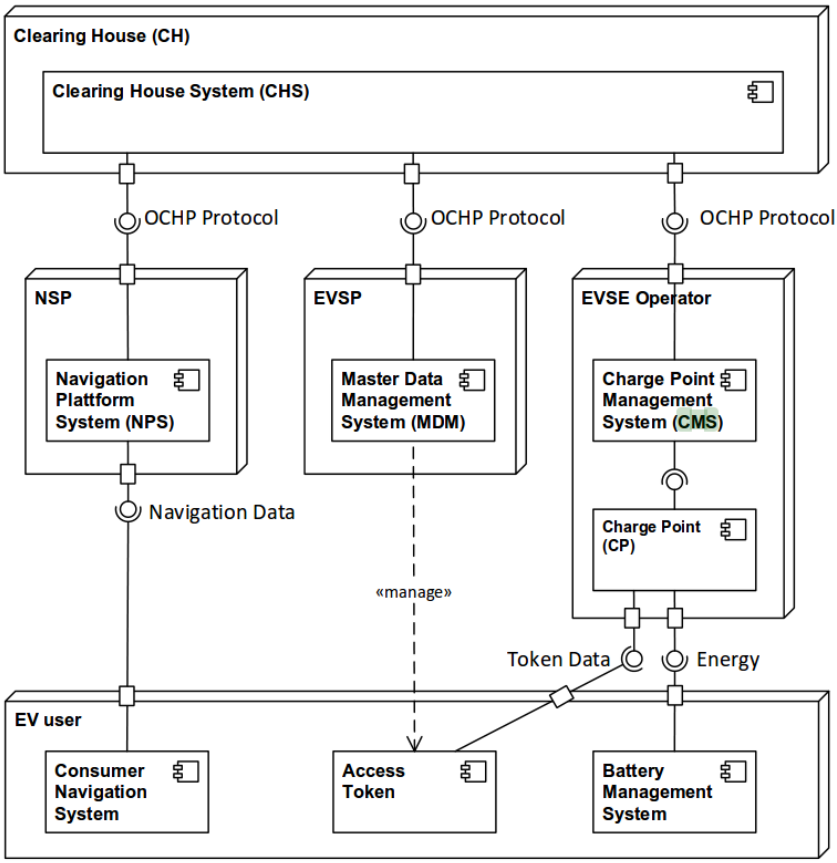


Figure 115. OCHP interfaces [119]

The definitions of the three involved actors, as written in the standard document, are the following:

- EVSP: the EVSP operates as a contract party for the EV user. The EV Service Provider takes care of the EV user authentication and billing processes. The EV Service Provider provides the EV-customer authorization tokens (i.e. RFID-card, certificates) that give authorisation to use the charging stations of contracted EVSE Operators.
- EVSE Operator: the EVSE operator operates as contract party for the EVSP. The charging stations (EVSE) of the EVSE operator are accessible by a specified set of EV users of the contracted EVSPs. The EVSP pays the EVSE operator for the charging services received by its contracted EV users.
- NSP: the NSP offers service towards the EV user for searching, locating and routing to EVSEs of the contracted EVSE operators. It therefore may have contracts with EVSE operators or EVSPs.

The usual sequence of interactions which the OCHP protocol enables is the following:

1. An EVSP (Partner A) uploads authorisation data of its EV users to the Clearing House (CH).

2. The EVSE operators that have a roaming contract with (A), download this authorisation data from the CH.
3. The EVSE operators enable these authorisations to be used on their charge points.
4. The EV users of partner (A) can now charge their electric vehicles at all charge points of the EVSE operators named in step 2.
5. The EVSE operator uploads the charge data (using Charge Detail Records) to the CH.
6. This charge data is then routed by the CH towards partner (A) using OCHP.
7. Partner (A) pays the roaming partner for the charging action done by its customer.
8. Partner (A) bills its customer.

In particular, OCHP is used in steps 1, 2, 5 and 6. The data exchanges between the three parties, which are mediated by the Clearing House, can be classified into the following four categories:

- Exchange of Authorisation Data
- Exchange of Charge Data, the raw billing data
- Exchange of Charge Point Information
- Live Authorization Requests

More in detail, the first category includes the following data exchanges:

- **Upload own authorisation data (roaming list) to the CH**: the MDM of each EVSP uploads the own authorisation data to the Clearing House to share that data with EVSE Operators.
- **Update own authorisation data (roaming list) in the CH**: for later updates of authorization data from the MDM to the Clearing House and the EVSE Operators, only the changed entries (delta) have to be transferred.
- **Download global roaming authorisation data from the CH**: a CMS downloads the global authorisation data repository from the CH.
- **Download updates in global roaming authorisation data from the CH**: a CMS downloads the changes to the global authorisation data repository since the last synchronization from the CH.

The second category includes the following data exchanges:

- **Upload charge data records**: local roaming charge data records are sent from the CMS to the CHS.
- **Download extracted roaming charge data records**: cleared roaming charge data records, held at the CH are sent from the CH to the MDM.

The third category includes the following data exchanges:

- **Upload own charge point information to the CH**: each CMS has to upload its own Charge point information to the Clearing House.
- **Download global charge point information from the CH**: a NPS downloads the global charge point information from the CHS.

The fourth category includes the following data exchanges:

- **Request the CH to authorize one single token for roaming**: a CMS requests the Clearing House to authorize one single token for a charging session.

All the OCHP messages are exchanged via SOAP (Simple Object Access Protocol), with security enforced by WS-Security.

8.5.8 SAE J 1939 (CAN protocol)

The most commonly used communication protocol to exchange information between vehicle electronic control units is CAN SAE J1939. Only for “short”, “simpler” and “cheaper” communications the LIN (Local Interconnect Network) protocol is used (heater, smart alternator, etc.). For some types of vehicles, like those deployed in agriculture, other standards (like the ISO11783 ISOBUS standard) may be followed.

In EVs, at least from M1 passenger cars to N1, N2, M2 and M3 (commercial vehicles), CAN communication is used, which is compliant with the CAN SAE J 1939 protocol specification. According to different CAN architectures and layers, standard automotive devices (e.g. Internal Combustion Engine, Transmission Control Unit, ABS, Electronic Stability Control, Body computer) could be connected with specific EV devices (i.e. Inverter, BMS, DC/Dc converters; Chargers).

In general each message contains name, sender, receiver, refresh timing according to functional needs and bus load and the info to be transmitted and received (according the standard) like the status, maximum voltage, maximum current, temperature, etc. as well as control bits.

CAN SAE J1939 communication can be used for subsystem handshaking, Human Machine Interface (on/off, brakes, accelerator, drive neutral reverse command), physical value request (power, torque, voltage, current), physical value feedback (actual torque, actual speed), as well as for “low speed” control loops like temperature control, average voltage limitation, etc. With specific HW tools for PC and with a CAN data logger, it allows also diagnosis, data logging, SW upload and parameter change.

Due to communication speed, 250 – 500 kBd, refresh timing around 100 ms and additionally required time (from microprocessor to transceiver, transmission time, time from transceiver to microprocessor) this communication cannot be used for voice, video or high sped control loops.

Regarding the HW, the following schemes could be considered:

- Transceiver scheme:

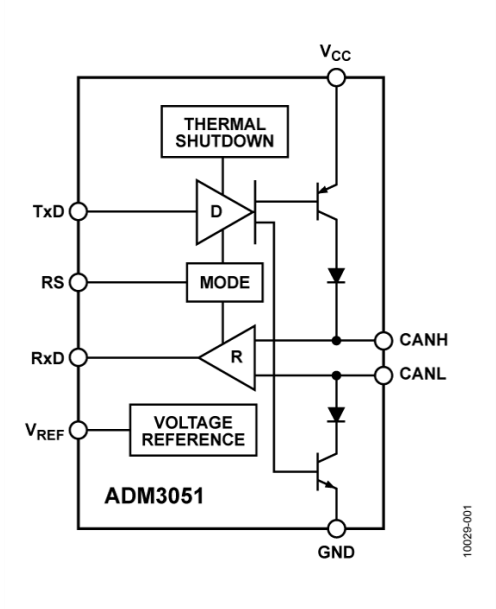


Figure 116. Transceiver Scheme of CAN Bus [120]

- Wiring schemes and HW: both the electric/electronic architecture and the HW minimize the common mode noise and the EMC disturbance, allowing for stable and safe communication on vehicles up to 18 m length, including power electronics. A main technical and integration requirement refers to chassis ground quality, shielded and twisted cable and shield ground connection.

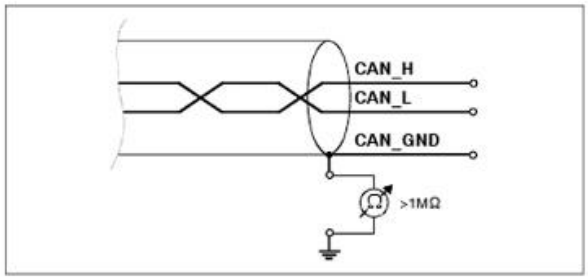


Fig.: Simplified schematic diagram of ground test measurement

Figure 117. Simplified schematic diagram of ground test measurement of CAN Bus [121]

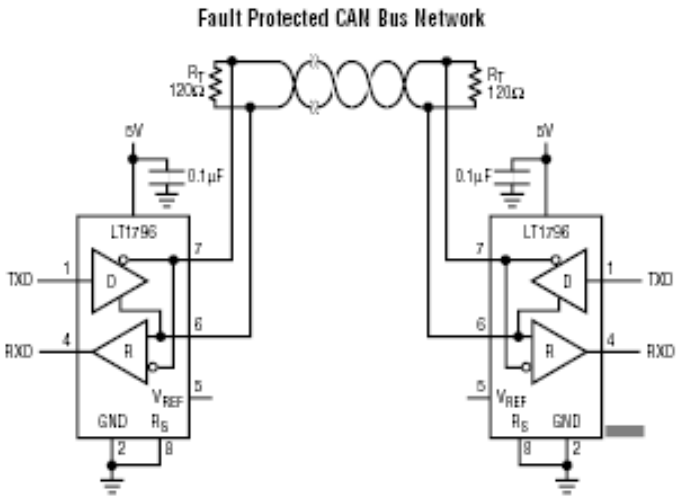


Figure 118. Fault protected CAN Bus network [122]

To have an idea on CAN architecture in EVs, below is presented an example related to mode 3 charging (communication according to IEC 61851-1). It should be considered that VDB (Vehicle Data Bus) CAN includes also standard vehicle subsystems, while EDB (Electric Data Bus) is specific for electric vehicle application. The available current data transmitted by the EVSE in form of PWM signal must be translated to a CAN SAE J1939 format message or directly acquired as value by the VMU (Vehicle Management Unit) electronic control. Making use of the PWM value, the inlet proximity pin resistance value and the current value required by the batteries (requested by the BMS (or MBS in the figure, where BMI means Battery Module Interface)), the VMU is able to define the current for the 3 chargers.

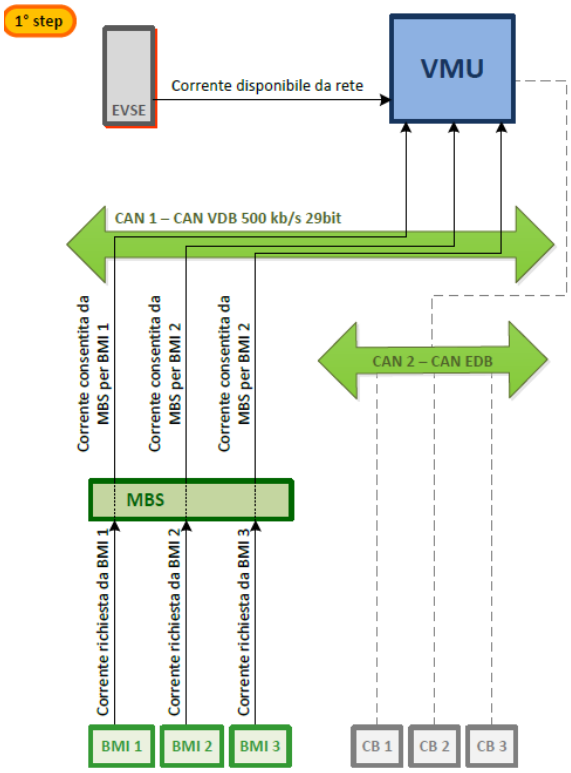


Figure 119. Mode 3 charging according in CAN Bus (source: Altra SpA engineering)

8.5.9 ETSI TS 101 556-1

This document [123] specifies the application responsible for the broadcasting of dynamic information from a roadside ITS (Intelligent Transport System) station or any other appropriate node (e.g. charging spot) to EV ITS stations, related to the availability and characteristics of the EV charging spots in the vicinity and/or surrounding areas of the vehicle.

Broadcasting is defined as a communication configuration attribute which denotes a point-to-multipoint mode of transmission, i.e. unidirectional distribution to all ITS Stations connected to the network and tuned for receiving.

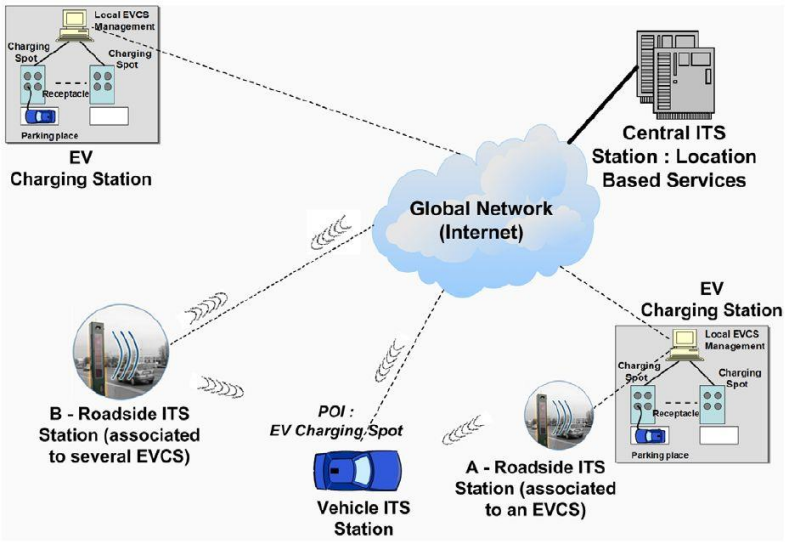


Figure 120. ETSI TS 101 556-1 Use case for the dissemination of the EVSE notification [123]

There are two types of ITS stations:

- Transmitting stations: the notification message originates either from the EVSE itself, from a central station, or from another appropriate ITS station.
- Receiving stations: the notification is received and processed b EV vehicle ITS stations.

Further interactions with the infrastructure and Central ITS stations, like reservation or payment of a charging spot are out of the scope of ETSI TS 101 556-1, but they will be another part of the global ITS system specifications.

Two **deployment scenarios** are considered (other are possible but out of the scope of the document):

- Scenario A: the roadside ITS station is connected to the local EV charging station management centre and collects in real time the dynamic information which will be broadcasted to all vehicles moving in the communication area of the ITS roadside station.
- Scenario B: a ITS roadside station provides dynamic information related to several EV charging stations located in a relevant area surrounding the ITS roadside station.

The non EV ITS stations which receive the message (conventional vehicles) discard it.

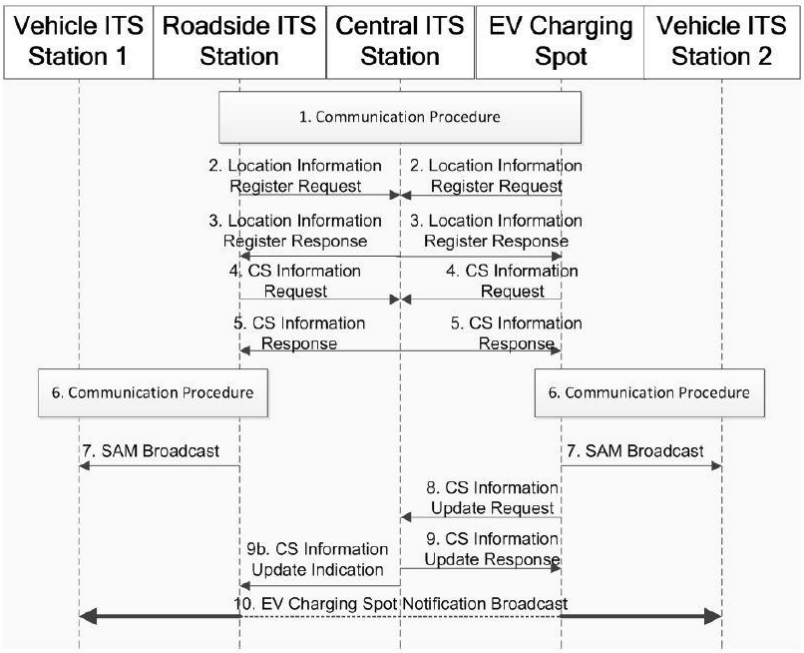


Figure 121. ETSI TS 101 556-1 Application flow diagram [123]

The EV charging spot notification complies with the format of POI (Point of Interest) Notification messages.

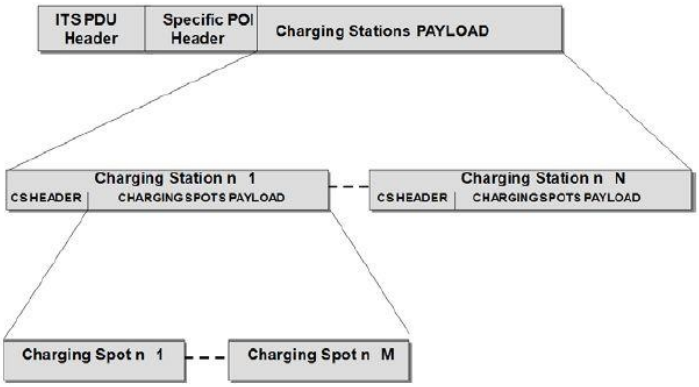


Figure 122. ETSI TS 101 556-1 General structure of the EVSE Notification message [123]

The message format is encoded in ASN.1. Unaligned packed encoding rules (PER) as defined in ITU-T Recommendation X.691 shall be used for encoding and decoding the message.

The **message format** makes use of the Common Data Dictionary as defined in the ETSI TS 102 894-2. The fields contained in the EVSE notification message are explained in the standard, below some of the exchanged data is shown:

- EV charging location (including digital map of the area)
- Opening days and hours
- Pricing
- Booking information contact
- Accepted payment methods

- Number of charging spots available
- Type of charging (mode, inductive stationary, inductive dynamic)
- Type of cables and sockets
- Energy availability (minimum and maximum per socket)

Two **communication profiles** that can be used to exchange the POI related notifications are the following:

- G5 Communication profile: applications implementing the ITS G5 (ETSI ES 202 663, 5GHz frequency band) communication profile comply with the following:
    - Transport protocol: basic transport protocol.
    - Network protocol: GeoNetworking, Topological Scoped Broadcast, single-hop.
    - Access technology: ITS G5B, channels can be either SCH3 or SCH4
- 3GPP Communication profile: applications implementing this profile should comply the following:
    - Transport protocol: UDP, RTP, TCP
    - Networking protocol: IPv6/IPv4
    - Access technology: LTE/HSPA/GSM

The standard defines very general requirements for security (confidentiality, integrity, availability, accountability and authenticity), conformance (related to ETSI conformance testing specification), performance (latency between transmission of message and treatment in the EV from 1 to 10 seconds), ITS Communication profile, interoperability, operational management and actors' responsibility.

In the document annex some informative examples are provided for **services** related to EVSE broadcasting:

- **Charging spot routing and notification service**: this is a proposal for an enhanced routing service, which goes beyond charging spot notification and requires bi-directional service channel. The use case can be divided in several sub cases that can be combined into one service:
    - Before or during the trip the user searches actively for a charging station in the vicinity of the destination.
    - Emergency scenario: the search is performed in the neighbourhood of the current location, being triggered by the context (state of charge, energy consumption, congested traffic, etc.) or resulting from a previous subscription (in case all stations are busy, the user may subscribe to receive a notification about charging spots that become available).
    - Economy charging: the service considers a location based notification about available charging stations, interesting offers, etc. The reservation of EVSE cannot be done earlier than a certain time before the expected arrival time (in order to avoid abuse).
- **Charging spot discovery application**: when the vehicle identifies a need for battery recharging or quick drop, or when the user intends to recharge or charge its battery, the charging spot discovery application is activated either directly by the vehicle electronic system or indirectly by the user via the HMI. The discovery might be performed by the analysis of received EVSE notification messages or by interrogating some central station through a cellular network. If the selected station is offering the possibility to book a socket, the charging spot booking application may be activated

and a booking and payment transaction may be started with the relevant central ITS station being in charge of this service. This transaction might be achieved using standard internet service based on IPv6. The availability of the EV charging spot notification service is announced using the Service Announcement facility of the Roadside ITS station. Upon reception of the relevant SAM (Service Announcement Message), announcing the notification, the vehicle ITS station charging spot discovery application will request the communication management to switch to the G5 channel assigned to the notification service. When the user has selected a charging spot, his navigation application may guide him to it.

- **Application functional entities implementation:**
  - ITS Central Station is responsible for location and communication based services provision for EV charging spot notification application. Location based services provision might be rely upon global EV charging spot's location information, DNS and web configuration. The communication with the Roadside ITS stations can be performed via Wi-Fi, 3.5G, WiMAX, etc.
  - ITS Roadside station: it typically sends local EVSE information and can diagnose information to the vehicle. The communication with the Vehicle ITS can be performed via ITS 5,9GHz (automotive IEEE 802.11p, Wi-Fi 5,9 GHz band reserved).
  - ITS vehicle station: it is typically roaming and it is connected to an ITS Roadside station and, while charging, to the EVSE through power lines.

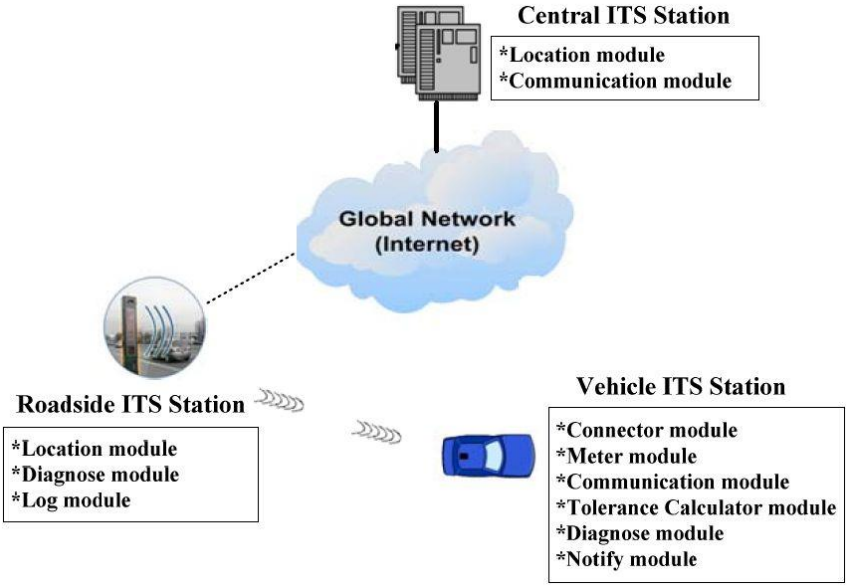


Figure 123. ETSI TS 101 556-1 Application functional entities [123]

- **Broadcasting using a cellular network**: The next figure depicts the EV charging spot systems using different communication links to send their information to a central ITS station. The central ITS station acts as an aggregator of information from several charging spots. LTE/eMBMS is used to broadcast the notification message in a service area of larger scale. In this use case the vehicle ITS station should be subscribed to a geo-referenced multicast group.

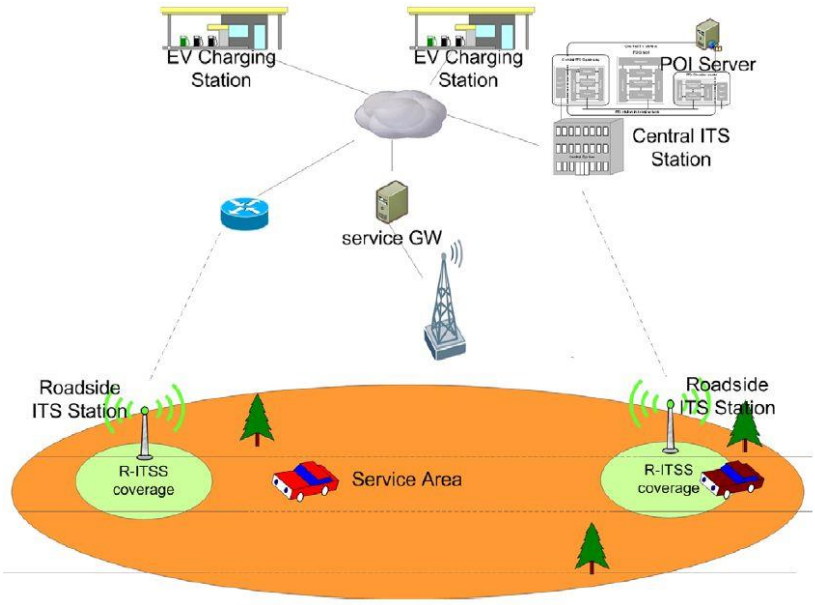


Figure 124. ETSI TS 101 556-1 Broadcasting using a cellular network [123]

8.6 Communication protocols

Table 34 shows the main communication technologies used in the smart grid context and the type of networks they are suitable for. In section 0 communication standards have been identified for different smart grid systems. In addition, some of the communication protocols analysed in the previous section define lower OSI levels.

The following table shows candidate communication technologies for component interaction.

Table 39 Candidate communication technologies

Interaction level	Candidate technology
EV user - EV	NFC, vehicle data bus CAN SAE J1939, Wi-Fi, Bluetooth, USB
EV user - EVSP	Wired or wireless connection to internet (web page, web service)
EV user – EVSE	RFID card, chip card, magnetic stripe cards, bar code, QR or barcode, NFC, vehicle data bus CAN SAE J1939, Bluetooth, credit card
EV – EVSE	Wired (PLC, pilot wire) or wireless (Wi-Fi, Bluetooth, Zigbee, infrared)
EV – Other actors, vehicles and/or infrastructures	WiMAX, digital cellular networks, radio, wireless mobile communications
EVSE – EVSE operator or hub	Wired (PLC, optic fibre) or wireless (radio, cellular networks)
EVSE hub – Other actors	Cellular networks or wired connection to internet*
EVSE operator – Other actors	Cellular networks or wired connection to internet*

Interaction level	Candidate technology
EVSP – Other actors	Cellular networks or wired connection to internet*

*Internet: Network (IPv4/v6, TCP, UDP, IPsec, ARP and FTP) and syntactical (SOAP, REST, XML, HTML, ASN.1 and SNMP)

However, most of the protocols above allow different data definition and they might even be ruled by different protocols. For example RFID systems could follow ISO/IEC 14443, ISO/IEC 15693 or ISO/IEC 18000 standards. Once selected the technology, the codification should also be made under interoperability requirements: which information fields are defined, with which length, where is the information stored in the card, how is defined the user ID in order for all EVSEs to be able to identify him/her and the car, etc.

The minimum required information is also an important aspect to fulfil interoperability. For example, in an identification and authentication process even if many fields could be exchanged, some of them should be obligatory. Still, a high number of requisites may cause that some users could not have access to the charging process.

8.7 Components – IOP needs table

On the basis of information collected in previous subchapters, the table of interoperability issues was created (Table 40). The table summarizes information about the current situation of EVs and the related infrastructure, indicating fields where interoperability issues may occur.

The analysis of the interoperability (IOP) issues was carried out on the basis of services and use cases developed from those presented in Table 36. Selection of use cases was conducted as to cover the majority of fields, where IOP issues may occur. The analysis of the all possible use cases is rather impossible to be handled and presented in report due to the large data sets.

The first two columns describe services selected for the analysis presentation. The next column presents use cases which takes place within the service (steps that allows for the provision of the service). Systems involved (regarding to all e-mobility) in each use case are presented in the next column. Fifth column indicates direct component which interoperability is assessed. The middle part of table presents a set of components which are used in analysis. The “X” addresses the components where the interoperability issue occurs. The last one column includes comments for components if necessary.

Table 40. Overview of interoperability issues according to different uses cases of EV recharging and V2G.

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
1	Home charging (mode 1) Dumb charging without identification, contract certificate update/installation, scheduling and target	Physical connection	EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A (61851-1 IEC:2010)
			Grid	domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A (61851-1 IEC:2010)
		Start of the charging process	EV user	User hand, finger, voice etc.				X																											
				External device: mobile phones etc				X																											
			EV	HMI platform															X			X													Regarding from communication method
				AC on-board charger						X																									
			Grid	Electrical installation		X																													
		Charging loop	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				HMI platform															X			X													
				AC on-board charger						X																									

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
1	Public charging (mode 1 & 2) Semi-dumb charging provided as open access without contract certificate update/ installation, scheduling and	End of charging process	EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A (61851-1 IEC:2010)
			Grid	domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A (61851-1 IEC:2010)
				Electrical installation		X																													
			EV	HMI platform															X			X													
				AC on-board charger						X																									
			EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
2			EV user	External device: mobile etc																												X			For distance identification
		EV/EV user identification, authentication and authorization		credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																
		Physical connection	EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
	target			domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
		Start of the charging process	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	HMI platform															X			X													Regarding from communication method
				AC on-board charger						X																									
			EVSE	Protection equipment		X																													
		Charging loop	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				HMI platform															X			X													
				AC on-board charger														X																	
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Protection equipment		X																													

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		End of charging process	EV	HMI platform															X			X													
				AC on-board charger						X																									
			EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
		Send charge details	EV user	External device: mobile etc																												X			For distance identification
				credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																
3	Public charging (mode 1 & 2) Basic communication charging provided with EV identification by card/phone and charging scheduling directly by the EVSP, without contract certificate update/	EV/EV user identification, authentication and authorization	EV user	External device: mobile etc																												X			For distance identification
				ID Card										X																					For direct identification at charging spot
				credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	HMI platform																	X														For direct identification at charging spot
				Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
	installation and target	Physical connection	EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
		Start of the charging process	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	HMI platform															X			X													Regarding from communication method
				AC on-board charger						X																									
				Energy management gateway													X																		
			EVSE	Protection equipment		X																													
		Communication setup	EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Energy management gateway													X																		
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		Charging scheduling		domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
			EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Energy management gateway													X																		
			EVSE	Connector	X																														
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																												
			EVSE Operator	billing system																													X		
				Energy management gateway																													X		
			EVSP	energy trading application																				X	X										
		Charging loop	EV user	User hand, finger, voice etc.				X																											In emergency opportunity
				External device: mobile etc				X																											In emergency opportunity
			EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				HMI platform															X			X													
				AC on-board charger														X																	

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
				Energy management gateway													X																		
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Protection equipment		X																													
				Energy management gateway			X																												
			EVSE Operator	billing system																													X		
				Energy management gateway																													X		
			EVSP	energy trading application																				X	X										
		End of charging process	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	HMI platform															X			X													Regarding from communication method
				AC on-board charger						X																									
				Energy management gateway													X																		
			EVSE	Protection equipment		X																													

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		Send charge details	EV user	External device: mobile etc																												X			For distance identification
				ID Card										X																					For direct identification at charging spot
				credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	HMI platform																	X														For direct identification at charging spot
				Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																
4	Public charging (mode 1 & 2) Basic communication charging provided with EV identification by card/phone and charging scheduling directly by the EVSP, without contract certificate update/ instalation and	EV/EV user identification, authentication and authorization	EV user	External device: mobile etc																												X			For distance identification
				ID Card										X																					For direct identification at charging spot
				credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	HMI platform																	X														For direct identification at charging spot
				Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
	target	Physical connection	EV	Inlet							X																									IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
			EVSE	Connector	X																															IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Plug									X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																								IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
		Start of the charging process	EV user	User hand, finger, voice etc.				X																												
				External device: mobile etc				X																												
			EV	HMI platform															X			X														Regarding from communication method
				AC on-board charger						X																										
				Energy management gateway													X																			
			EVSE	Protection equipment		X																														
		Communication setup	EV	Inlet							X																									IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Energy management gateway													X																			

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Plug									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
		EV conctract certificate update or instalation	EV	HMI platform												X																			
			EVSE	Communication system equipment (DEVICES + PROTOCOLS)				X																		X									
			EVSE Operator	Customer management system												X																	X		
			EVSP	Energy trading application																						X									
		Target setting	EV	HMI platform												X																			
			EVSE	Communication system equipment (DEVICES + PROTOCOLS)				X																											
		Charging scheduling	EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)
				Energy management gateway													X																		
			EVSE	Connector	X																														

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		Charging loop		domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																												
			EVSE Operator	billing system																													X		
				Energy management gateway																													X		
			EVSP	energy trading application																				X	X										
			EV user	User hand, finger, voice etc.				X																											In emergency opportunity
				External device: mobile etc				X																											In emergency opportunity
			EV	Inlet							X																								IOP only if connection of EVs using cable is carried out in accordance with Case B (61851-1 IEC:2010)
				HMI platform															X			X													
				AC on-board charger														X																	
				Energy management gateway													X																		
			EVSE	Connector	X																														IOP only if connection of EVs using cable is carried out in accordance with Case B and Case C (61851-1 IEC:2010)

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
				domestic single-phase plug					X																										IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				domestic single-phase socket									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Protection equipment		X																													
				Energy management gateway			X																												
			EVSE Operator	billing system																													X		
				Energy management gateway																													X		
			EVSP	energy trading application																				X	X										
		End of charging process	EV user	User hand, finger, voice etc.				X																											
				External device: mobile etc				X																											
			EV	HMI platform															X			X													Regarding from communication method
				AC on-board charger						X																									
				Energy management gateway													X																			
			EVSE	Protection equipment		X																													
		Send charge details	EV user	External device: mobile etc																												X			For distance identification
				ID Card										X																					For direct identification at charging spot

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
				credit card, cash, loyalty card, mobile - for payment											X																				For payment
			EVSE	HMI platform																	X														For direct identification at charging spot
				Payment equipment (credit card, NFC, ...)																X															
			Credit Card Operator	Credit Card payment system											X																				
			EVSP	customer portal															X																
5	Day-ahead/Intraday load management by the EVSE Operator to provide avoidance of grid overloads contracted directly and activated by EVSE Operator	Send network info or support request	EVSE Operator	Energy management gateway																								X							
			DSO	Energy management gateway													X																		
		Check willingness to provide service	EV user	External device: mobile etc													X																		
			EVSE Operator	Energy management gateway													X																	X	
			EVSP	Asset management system																					X										
		Confirm service (un)availability	EVSE Operator	Energy management gateway																								X							
			DSO	Energy management gateway																					X										
		Request service activation	EVSE Operator	Energy management gateway																								X							
			DSO	Energy management gateway																					X										

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		Check technical feasibility	EV	inlet							X																								
				Energy management gateway													X																		To check is charger regularable
				AC on-board charger													X																		
			EVSE	Connector	X																														
				plug									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																												
			EVSE Operator	Energy management gateway													X																		
		Confirm service feasibility	EVSE Operator	Energy management gateway																							X								
			DSO	Energy management gateway																				X											
		Send schedule and grid location for EVSEs	EV user	External device: mobile etc													X																		
			EVSE Operator	Energy management gateway													X																		
				Customer management system																													X		
				GIS (Geographical Identification System)																										X					
			DSO	GIS (Geographical Identification System)																						X									
				Energy management gateway																				X											

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
				Scheduling application																						X										
		Confirm schedule (in)validity	EV user	External device: mobile etc													X																			
			EVSE Operator	Energy management gateway													X																			
				Customer management system																													X			
				GIS (Geographical Identification System)																											X					
			DSO	GIS (Geographical Identification System)																							X									
				Energy management gateway																					X											
				Scheduling application																						X										
		Provide load management	EV	inlet							X																									
				Energy management gateway													X																			To check is charger regularable
				AC on-board charger													X																			
			EVSE	Connector	X																															
				plug									X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																								IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																													
			EVSE Operator	Energy management gateway													X																			

					EV				GRID		EVSE								EV user					EVSEO			DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
		Accept service	EVSE Operator	Energy management gateway																							X							
			DSO	Energy management gateway																					X									
		Infrom about service provision	EV user	External device: mobile etc																											X			
			EVSE Operator	Energy management gateway																							X					X	X	
			EVSP	Asset management system																					X									
6	Day-ahead/Intraday V2G by the EVSE Operator to provide avoidance of grid overloads contracted directly and activated by EVSE Operator	Send network info or support request	EVSE Operator	Energy management gateway																							X							
			DSO	Energy management gateway																					X									
		Check willingness to provide service	EV user	External device: mobile etc																												X		
			EVSE Operator	Energy management gateway																							X					X	X	
			EVSP	Asset management system																					X									
		Confirm service (un)availability	EVSE Operator	Energy management gateway																							X							
			DSO	Energy management gateway																					X									
		Request service activation	EVSE Operator	Energy management gateway																							X							
			DSO	Energy management gateway																					X									
		Check technical feasibility	EV	inlet							X																							
				Energy management gateway													X																	To check is charger regularable
				AC on-board charger													X																	
			EVSE	Connector	X																													
				plug									X																					IOP only if connection of EVs using cable

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
													X																							is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																												
			EVSE Operator	Energy management gateway													X																		
		Confirm service feasibility	EVSE Operator	Energy management gateway																							X								
			DSO	Energy management gateway																				X											
		Send schedule and grid location for EVSEs	EV user	External device: mobile etc													X																		
			EVSE Operator	Energy management gateway													X																		
				Customer management system													X																		
				GIS (Geographical Identification System)																										X					
			DSO	GIS (Geographical Identification System)																						X									
				Energy management gateway																				X											
				Scheduling application																					X										
		Confirm schedule (in)validity	EV user	External device: mobile etc																												X			
			EVSE Operator	Energy management gateway													X																		
				Customer management system		X																													
				GIS (Geographical Identification System)																										X					

					EV				GRID		EVSE								EV user					EVSEO				DSO				EVSP			
No.	Service	Use case	Systems involved	Components for IOP issue	inlet	AC on-board charger	Energy management gateway	HMI platform	domestic single-phase socket	Electrical installation	Connector	Plug	socket outlet	Human Interface (Front end portal)	Payment equipment (credit card, NFC, ...)	Communication system equipment (DEVICES + PROTOCOLS)	Energy management gateway	Protection equipment	External device : mobile etc	credit card, cash, loyalty card, mobile - for payment	ID Card	User hand, finger, voice	Credit Card Operator	billing system	Energy management gateway	Customer management system	GIS (Geographical Identification System)	Energy management gateway	SCADA	Scheduling application	GIS (Geographical Identification System)	Customer portal	Energy trading application	Asset management system	Comments
			DSO	GIS (Geographical Identification System)																							X								
				Energy management gateway																					X										
				Scheduling application																						X									
		Provide load management	EV	inlet							X																								
				Energy management gateway													X																		To check is charger regularable
				AC on-board charger													X																		
			EVSE	Connector	X																														
				plug									X																						IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Socket outlet								X																							IOP only if connection of EVs using cable is carried out in accordance with Case A and Case C (61851-1 IEC:2010)
				Energy management gateway			X																												
			EVSE Operator	Energy management gateway													X																		
		Accept service	EVSE Operator	Energy management gateway																								X							
			DSO	Energy management gateway																					X										
		Inform about service provision	EV user	External device: mobile etc													X																		
			EVSE Operator	Energy management gateway																													X	X	
			EVSP	Asset management system																					X										

The interoperability table presents 6 different services which advancement level is different, starting from the most simply service “Home charging (mode 1), Dumb charging without identification, contract certificate update/installation, scheduling and target”, and finishing at significantly complicated V2G service (“Day-ahead/Intraday V2G by the EVSE Operator to provide avoidance of grid overloads contracted directly and activated by EVSE Operator”).

The first service refers to pure charging by mode 1 with the usage of typical domestic plug and socket. The charging process is fully managed by BMS system. Therefore interoperability issue only applies to the connection of EV and electrical installation at home (which in general is fulfilled).

More serious issues occur for services 2, 3 and 4 where the type of connector and inlet decides if EV charging is able to be performed or not. In this cases it may happen that the inlet type can be different than the connector type in which charging station is equipped with. Even if the inlet and connector are compatible it does not ensure interoperability between components of the rest of the systems involved. It should be highlighted that the pairs of components presented in the table are the part of a chain of components used for the service provision. If the interoperability between two components is not preserved, entire service can be not able to be provided or can be provided in a wrong way. The highest risk of lack of the interoperability is for V2G, where there are still the lot of organizing gaps (lack of defined procedures) related with the novelty of the service.

According to the table 40 and to the content of the report, the most important interoperability issues refer to communication between actors and involved systems for service provision needs, between charging station and other actors involved such as DSO, clearing house, EVSP, EV user. Services which should to be analysed can be grouped in two categories:

- Services already existing
- New envisaged services

For the first category services (already existing) interoperability issues may occur between the following components:

1. EV user: External device: mobile phone, etc. --- EV: HMI platform

   The external communication is essential for the EV user to get remote access to information about EV, i.e. about the battery SOC of the EV batteries or to receive a massage when batteries are fully charged. The interoperability is related with connection establishment and functionalities when the connection is set.

2. EV user: Credit card, cash, loyalty card, mobile - for payment --- EVSE: Payment equipment (CREDIT CARD, NFC)

   The issue refers to EVSE payment equipment which cannot support all of the payment methods used within the Europe. It is common for credit cards that the number of providers is high.

3. EVSP: Customer portal --- EV user: External device: mobile, etc.

   Because of discrepancies in the available software of mobile devices it may happen that EV user will not be able to Log in into the EVSP customer portal.

4. EVSE: HMI Platform --- EV user: ID Card.

EV users commonly use loyalty cards for identification. However the number of EVSPs providing loyalty programs is wide and ID cards may not be compatible with any HMI platform at EVSE.

5. EVSEO: Billing system --- EVSP : Energy Trading Application.

   If the ID card would be compatible with HMI platform (see issue 4) but EVSE operator do not have suitable equipment for communication with EVSP.

6. EV user: External device: mobile phone, etc. --- EVSP: Energy Management Gateway.

   If EV user would like to receive an information from EVSP that his/her car is ready for a ride.

7. EVSEO: Customer management system --- EVSP: Energy management gateway.

   When the EV user is able to provide V2G service, he has a contract with EVSP but EVSE Operator does not have a proper customer management system, which is able to inform EVSP about willingness of V2G.

The second category includes following services involving components between which interoperability issue may occur:

8. EVSEO: Energy Management Gateway --- DSO: Energy Management Gateway

   This is one of the most important interoperability issue which must be solved to make V2G able to provide. There is no strictly specified which protocol and what hardware would be used. There are some solution proposed i.g. IEC 61850.

9. EVSEO: Geographical Identification System --- DSO: Geographical Identification System

   The issue refers to geographical identification of EVSEO by the DSO. The software and hardware used by EVSEO and DSO can be different and do not ensure interoperability.

10. DSO Scheduling Application --- EVSEO: Customer management system

    Scheduling Application used by DSOs are dedicated application for specified needs. There are wide discrepancy of the standards and protocols used in the EU. The same solution should be introduced for DSOs and for EVSO to make sure that the EVSEO can be included in the DSO schedule.

8.8 Summary

All different categories, defined by layers in the SGAM, interact when defining an e-mobility use case. Use cases can be considered at different levels, from the most general functionality or service description to the elementary cases that shape them. Even if most general cases like those presented in this chapter might be limited (not all possibilities have been described though), their feasibility and implementation is conditioned by business and regulatory aspects.

Regulation is still part of the electricity sector and it affects energy distribution and transmission. Network operation procedures, network fees definition, compensation of the regulated activity, market participation requirements, role definition... they all affect business development possibilities. Apart from this, the interaction between the different market

players might be also affected by the roles that can be assumed by any of them. However, when speaking about player interaction, it might be a better option to use roles instead of players, since these might be common to most regulatory environments.

Regulatory aspects are crucial for new business models to arise. These will be based on service provision, which rely partially on the ability to carry out certain functionalities at technology level. These functionalities are more and more linked to ICT systems and their interaction. Therefore, appropriate communication standards will permit the development of functionalities and services related to actors' business models, while the lack of them might hinder or make difficult their deployment.

Considering all possibilities, the amount of use cases and the interaction between actors and systems is huge. At the same time, it seems that existing standards, even if still evolving, can already provide many added value services. The message exchange defined by the ISO 15118 permits Smart Charging, taking into consideration the preferences of both the EV user and the network and allowing an optimization of the process. However, it involves the participation of several actors and data sources. The OCCP v2.0, with respect to previous versions, achieved to support new use cases that were defined by the ISO 15118 standard and, as consequence, it extends the communication domain from the EVSE towards the EVSEO.

However, the inconsistencies between existing protocols are likely to result in (future) interoperability problems. Several protocols exist at network level, ITS, e-mobility... that seem to be, at least, a good basis for functionalities development but their diverse philosophies might complicate their use within an end-to-end communication.

On the other hand, it remains certain that higher interoperability levels require higher implementation efforts. It might happen that, through different functionalities, similar services could be offered, or at least, services meeting the objectives set by DSOs, EV users or any other actor. For example, CP location could be offered by ITS systems or through secondary actor front-ends; Smart Charging could be performed through smart (ISO/IEC 15118) or basic (IEC 61851-1/23) communications; etc.

Similarly, more complex procedures require more complex testing procedures definition and implementation, but it is important to observe the market approach in a certain environment, in order to be able to provide the most adequate services at lower cost.

Presented in the end of the chapter, interoperability table indicates on plenty of interoperability issues which may occur in different parts of the EU. However the most relevant issues refer to ICT systems used by EV users and EV, EVSE, EVSP. The second important area of interoperability which should to be investigated is communication between EVSE/EVSP and DSO. Especially that the area is still not defined, there are not specified what services DSO would be interested in and what procedures would be used.

Summing up, an eye should be set on standard development and on market adoption of standards. This will permit to offer suitable services to foster interoperability and market development in the e-mobility sector. Flexible test architectures will help achieve these objectives by permitting the implementation of evolving protocols and market approaches, especially in the field of high level information protocols.

9 INTEROPERABILITY RELATED RECOMMENDATIONS FROM THE ENERGY SECTOR, INFRASTRUCTURE PROVIDERS AND ACEA

This chapter provides recommendations regarding the EV interoperability problem avoidance in Europe and other countries according the OEM's point of view. It refers and uses as reference two official European Automobile Manufacturer's Association (ACEA) documents on EV: "position paper on electrically chargeable vehicles" and "position and recommendations on connector types (IEC 62196), charge modes (IEC 61851) and communication standards for the charging of electrically chargeable vehicles (passenger cars and light-commercial vehicles)"

9.1 Energy sector and infrastructure providers

Without an appropriate recharging infrastructure electrically chargeable vehicles cannot successfully be introduced in the market. The public sector, infrastructure providers and the energy sector will have to build up a recharging infrastructure as a prerequisite for customer's acceptance of electrically chargeable vehicles. An appropriate infrastructure delivers the availability and necessary density of recharging possibilities. Customers should have the free choice between different energy suppliers (from which utility they get their electricity) and access to all charging stations independently of the charging station provider or the energy provider (e.g. national/international roaming). Customer-friendly operation, billing and payment systems need to be EU wide harmonized.

In the future it will be important to charge vehicles in an intelligent manner in order to prevent charging at peak loads for the power networks and to allow customers recharging at low costs.

As far as possible future options are concerned, the vehicle battery may be used to feed energy back into the grid whenever the price of energy is particularly high or there is a need for additional V2G services. Many technological, safety and legal issues still have to be resolved up till then (e.g. negative effects on the durability of the battery and consumer convenience). The priority of the automobile industry is to charge the vehicle while optimizing battery life. However, vehicle batteries might under the right circumstances and conditions be able to serve as bi-directional energy storage devices.

The following three main tasks and requirements for the charging infrastructures and energy sector were identified:

1. availability/ sufficient density of the charging infrastructure (home/depot, city, along motorways, work places, etc.) and consumer convenience,
2. conditions of use that do not compromise the flexibility, the affordability and the comfort of charging,
3. the optimized sharing of renewable electricity usage for charging increase the benefits of electrically chargeable vehicles.

9.2 Global regulatory framework and harmonization

Comprehensive standards and norms are required to ensure that the vehicles can be easily connected to the grid in order to recharge the EV's energy storage system. The goal must be to establish worldwide standards in order to avoid market fragmentation and to reduce costs (economies of scale)**.** The automotive industry already announced its proposal towards harmonized system for the EV charging and calls for quick progress in EU and global standardization activities including the involvement of the International and European Standardization Bodies.

Standards and common interfaces need to be agreed across Europe as a whole to avoid a fragmented pattern of local competing and incompatible solutions. This would provide the European industry with a unique opportunity to establish themselves as world leaders in electrically chargeable vehicles and related transport systems.

Additional technical issues with a need for EU-wide and possible global harmonization:

- standardization (plug, data protocol),
- cross-national compatibility,
- data protection (personal, business),
- safety requirements for recharging/discharging places,
- safety requirements while recharging/discharging the battery, e.g. short circuits,
- charging cable at the car or at the recharging station,
- technical approval body for recharging places,
- periodic inspections & maintenance of recharging places,
- liability clarification,
- convenient billing systems.

The technical requirements for the type approval system of electrically chargeable vehicles have to be extended and harmonized. The vehicle manufacturers support the use of UNECE Regulations for electrically chargeable vehicles type-approval, and assume that some of the necessary Regulations, in addition to Regulation 100, will be made mandatory in the framework of the implementation of the General Safety Regulation.

Referring in deeper on electric vehicle recharge several points concerning recharging interoperability are underlined in the "position and recommendations on connector types (IEC 62196), charge modes (IEC 61851) and communication standards for the charging of electrically chargeable vehicles (passenger cars and light-commercial vehicles)".

9.3 EV charging

There is a need to divide the EV expansion timeframe into two fundamental phases:

- ongoing period till approval (and broad acceptance) of relevant standards (Phase 1),
- relevant standards are approved, followed by sufficient lead-time resulting in first compliant implementations (Phase 2).

Phase 1 and Phase 2 are for passenger and light commercial vehicles and refers to AC and DC conductive charging.

9.3.1 Phase 1

Reflects current situation and should be seen as a preparatory step for a broader introduction of electrically chargeable vehicles in the EU. Public authorities are welcomed to consider the voluntary agreement made by the industry and pilot projects in urban areas should be streamlined on the infrastructure side accordingly.

9.3.1.1 **Phase 1 AC charging**

No restrictions on the type of vehicle inlet as vehicles with the different types are already on the market or in a late development phase. The manufactures will provide at least one cable with Type 2 plug (Mode 3) or standard domestic plug (Mode 2) to connect to the existing infrastructure. For public charging the Type 2 connectors and Mode 3 are recommended.

9.3.2 Phase 2

In phase 2, it is presumed that a uniform (EU) solution is available, enabling global charging standards to be applied reducing the variety of solutions in the market.

- Harmonized rules for phase 2 should apply for new vehicle types starting 2017, providing the industry with needed lead time to implement these new solutions in their vehicle development programs and to make necessary adaptation in the infrastructure.
- In line with the joint EU-US TEC discussions it is presented a definition of global vehicle inlet “envelope” as a key step for global solution, enabling simple switch between US and EU standards (see subchapter 2.3.2.1).
- Concerning the connector types/modes and communication, the following key principles and recommendations are suggested:
    - As for proposed uniform EU solution (Phase 2 starting in 2017 for all new vehicle types on vehicle side), ACEA suggest Type 2/Type 2 Combo to be used in the EU as a standard for AC/DC charging both on the vehicle and public charging side as long as it meets required national safety requirements.
    - Standardization of joint “envelope” profile paves the way to real global solution. Having in mind too different operational conditions (namely from the side of grid and electricity power in grids), simple single solution cannot work between US and EU. Joint “envelope” profile facilitates the exchange of Combo 1/Combo 2 solutions and will lead to significant simplification of charging mechanisms for consumers and cost reductions for the industry.
    - No direct communication between vehicle and grid is foreseen for the moment
    - PLC communication between EV and EVSE shall be ISO/IEC 15118 compliant.
    - If in the future communication between EV directly to the grid will be established, it shall follow an international standard (to be defined, but the EV-EVSE part should be compliant with ISO/IE C 15118).

- International standards ISO/ IEC 15118 and IEC 61851-23/-24 shall cover the needs of communication for most modes of charging.
- As for the communication technology, ACEA decided to concentrate all efforts on IEEE 1901 Profile Green PHY using the CPLT/PE.
- For the wireless communication, industry decided to select a PLC technology for the communications, wireless solutions should be developed in the future or for the moment will represent additional company specific extensions and business cases.

9.3.2.1 **Phase 2 AC (standard) charging:**

As for the harmonized solution, it is strongly recommended to unify national regulations concerning socket outlet types (e.g. some countries demand a shutter, whereas most countries don't). All accepted solutions shall comply with this global (harmonized) solution, therewith ensuring that the agreed ways of charging (single and three phase AC) will be supported throughout Europe. Harmonized rules for phase 2 are presumed to be applicable for new vehicle types with an introduction date in 2017 or later.

Type 2 (Mode 3) uniform EU solution in global "envelope" if opted by manufacturer.

Type 2 (Mode 3) uniform EU solution recommended for public charging.

Standard home charging, domestic plug (Mode 2), should be still allowed/supported as in phase 1.

9.3.2.2 **Phase 2 Fast charging**

Phase 2 includes "fast AC charging" up to 43 kW – mode 3 and "fast DC charging - mode 4. It is strongly recommended that those charging points are equipped with a fixed cable that is in line with existing standards.

Recommendation for the vehicle inlet: Type 2 or Combo2 connector in global "envelope" as defined in subchapter 2.3.2.1

Recommendation for public and fleet chargers: Charging points equipped by fixed cables with Type 2 or Combo2 connector.

Recommendation for home charging: Charging points equipped by fixed cables with Type 2 or Combo2 connector.

Remark: The development of public infrastructure shall not ban vehicles already equipped with other existing DC charging devices (e.g. CHAdeMO) and backward compatibility solutions for those vehicles should (at least) be considered.

9.4 Communication protocols for AC/DC charging

Communication is essential for charging electric vehicles. Basic communication for AC - mode 3 and DC - mode 4 should be in line with the IEC 61851-1 standard that has to be applied on all charging stations. The detailed specification of ISO/IEC 15118 enables reliable

charging using this standard. This standard supports different use cases like smart grid integration, roaming for charging abroad and also guarantees customer privacy, authentication and identification purposes. ISO/IEC 15118 describes communication between the car and the infrastructure (charging point) using IEEE 1901 Profile Green PHY on CPLT/PE. ISO/IEC 15118 does not include and describe any further details for enabling the infrastructure behind the charging point for smart grid solutions, for roaming services and so on, and it also does not include any details of the internal process of handling the data of this ISO/IEC 15118 protocol inside the car and the Control Units being part of the car.

9.5 Specific tasks to be done to ensure interoperability

Direct V2G communication (without EVSE)

No direct communication between vehicle and grid is foreseen, only vehicle in charging mode is considered and this has to be in-line with all safety standards, through harmonized hardware.

V2G communication using EVSE (including wall-boxes)

Independent of future standards, many technological, safety and legal issues still have to be resolved concerning two-way communication and energy flow between vehicle and grid (negative effects on the durability of the battery, the power grid, consumer convenience, privacy, warranty on the battery etc.). A large number of communication options are being considered and implemented (based on both wired as well as wireless technology). These solutions are expected to rapidly evolve and change over time.

The ISO/IEC15118 standard for EV-EVSE communication is considered by ACEA as the baseline for V2G communication.

Communication technology (data link layer) and physical layer

Concentrate all efforts on of IEEE 1901 Profile Green PHY on CPLT/PE to be operational as soon as possible.

Note: If the vehicles are charged under Mode 1 or Mode 2, no such communication should be mandatory to enable charging. Also for mode 3 and mode 4 high level communication shall not be mandatory. Business cases shall be the major drivers for supporting V2G (high level) communication.

Wireless communication for conductive charging

OEMs have decided to focus on PLC technology for the EV/EVSE communication first. Further investigations are required to assess the future for wireless communication.

It can however already be said that wireless communication is likely be used (first) in combination with wireless charging (e.g. inductive charging) and also for technology specific extensions, such as self-connecting conductive charging solutions for (city) busses. The general perception is that for these and similar applications it is required that the domain of technological solutions evolve first into a few technologically mature solutions before major standardization efforts are being spent. Nevertheless the perception is that whatever technological solution evolves, the basis of the applicable standard shall be a derivative of ISO/IEC15118.

9.5.1 Terminology

To ensure clear communication, ACEA is stressing the use of common terminology for connectors (sockets and plugs), see Subchapter 2.3.2.

10 OVERVIEW OF EXISTING TESTING INFRASTRUCTURE AND RELATED TESTING CAPABILITIES AT INTERNATIONAL LEVEL ON EV INTEGRATION

According to the European Roadmap on Electrification of Road Transport (2012) about 30% of all primary energy is consumed by the transportation sector [124]. This transforms the electric vehicle (EV) into one of the key players of the current decarbonisation process at the energy sector level in Europe. The EV deployment will require in the coming years a huge investment in EVs and infrastructure (i.e. EV supply equipment (EVSEs), its backend and the electricity grid). Efforts are also required in order to be able to assess the performance of EV systems, harmonize the grid-connectivity and communication standards, lower the development cost, promote the interoperability and increase the consumer confidence. The US Department of Energy (DOE) and the European Commission have agreed on three key areas of technical harmonization – Interoperability, vehicle test procedures and battery test procedures [115].

10.1 Power systems related testing infrastructure and equipment available within COTEVOS Consortium

For the purpose of performing performance, reliability and safety tests for EVs and batteries, the standard testing infrastructure for conventional combustion engine cars can also be used, for instance for motor test and roller dynamometer test, central unit control, climate chamber, etc. Additional testing infrastructure including simulation environment as well as its corresponding test cases are needed along with conventional test facilities mentioned above, especially when it comes to grid connection and related interoperability issues of EV.

In the COTEVOS project, the concepts, capacities and methods for testing EV systems will be developed and the related interoperability aspects in the smart grid context will be tested. The EV is one of the electrical units of smart grids and therefore the resulting strong interaction with the electrical grid needs to be particularly tackled. Table 41 shows the list of available simulation environments as well as its corresponding power grid testing facilities among COTEVOS partners.

1. TECNALIA Centre for Development and Demonstration of DER technologies – Derio (E)
2. AIT SimTech – Wien (A)
3. DTU PowerLabDK – Lyngby (DK)
4. IWES DeMoTec – Kassel (D)
5. TULodz Laboratory of Distributed Energy Resources – Lodz (PL)
6. RSE DER Test Facility RSE – Milano (I)

Table 41 Power grid testing facilities- detailed functionalities among COTEVOS partners

COTEVOS' consortium power grid test facilities							
		1	2	3	4	5	6
List for Simulation environnement-SE							
Physical network							

COTEVOS' consortium power grid test facilities							
		1	2	3	4	5	6
	Software Simulation of electrical power system		X	X		X	
	Real time Emulation of parts of the electrical power system	X	X	X	X		X
	Configurable simulation/emulation topologies	X	X	X	X	X	X
	Interface power simulators		X				
	Controllable load, generators, and storage systems	X	X	X	X	X	X
Actors							
	Simulator of prosumers as single entities		X	X		X	X
	Simulator of prosumers as aggregated entities	X	X	X			
	Metering services		X			X	
	SCADA	X	X	X	X	X	X
	EMS - Energy Management Systems	X		X	X		X
	Human Machine Interface	X	X	X	X		X
	Communication infrastructure protocols	X	X	X	X		X
	Business logic (profile clustering, algorithms, SLAs, etc.)						
	Business Management Systems						
	Administrative data (as for billing)						
External information							
	Weather module,		X				
	Real weather data for simulation		X				
	Energy market module						
	Real Energy market data for simulation						
	Utility requirements module						
Logging and database							
	Logging feature of performance and results	X	X	X	X	X	X
	Logging of messages and numerical simulation data		X	X	X		X
	Metrics extraction from (database stored) logging data			X	X		X
	Logging interface between physical and market layer						

List for Testing Infrastructure - TI							
Power level							
	Real electrical power system / network	X	X	X	X	X	X
	Generators (renewables, conventional) / power plants	X	X	X	X	X	X
	Electrical energy storage Systems	X	X	X	X	X	X
	Flexible connection and configuration	X	X	X	X	X	X
	Transmission substations (including measurements/switchgear)		X	X			
	Distribution network/Medium Voltage (Meshed or radial)	X		X	X		X
	Double switches for isolation of feeders / networks			X			
	Independent power supply from external/ high voltage generators			X			
	Primary distribution substation / medium voltage			X			
	Secondary distribution substation / low voltage	X	X	X	X		X
	Controllable power loads (High Voltage)		X				
	Distributed Energy Resources	X	X	X	X	X	X
	Full configurability of grid topology / medium voltage				X		
	Full configurability of grid topology / low voltage	X	X	X	X	X	X
	Energy market module						
	Real Energy market data for simulation						
Communication/monitoring level							
	Electrical measurement equipment and SCADA	X	X	X	X	X	X

COTEVOS' consortium power grid test facilities							
		1	2	3	4	5	6
	Data archiving		X	X	X	X	X
	Communication system technologies	X	X	X	X	X	X

COTEVOS participants' infrastructure presents strong capabilities in terms of covering the majority of EV grid connection related research and testing. However, the simulation and testing environment related to business models, administrative (e.g. billing) issues, or to other issues concerning the energy market are under development. The power supply and communication/monitoring levels are also covered by COTEVOS participants, while the energy market related issues are to be focused on during the project activities lifetime.

10.2 EV and EVSE related testing infrastructure available internationally

In order to collect the relevant information on the globally existing EV related research infrastructure, a survey has been conducted via on-line research as well as via direct contact with relevant institutes which were asked to fill in a dedicated form (Annex I).

Apart from the extensive information collected concerning the EV/EVSE testing capabilities of the DERlab member institutes and project partners which is available in the afore-mentioned database, further information research has been mainly focused on the countries which are currently the most advanced concerning EV/EVSE research and testing. The research infrastructure available in the COTEVOS Consortium is also listed and analysed. The targeted institutions have been mainly research institutes and testing and certification bodies. EV and EVSE manufacturers were also in the focus of the performed information research; nevertheless such companies' related information is not publicly available.

The outcome of the above-mentioned effort is summarized in the following subchapters.

10.2.1 Research sector

10.2.1.1 **Argonne National Laboratory (US)**

Argonne National Laboratory is the U.S. Department of Energy's lead national laboratory for the simulation, validation and laboratory evaluation of plug-in hybrid electric vehicles and the advanced technologies required for these vehicles.

Argonne's Advanced Powertrain Research Facility (APRF) enables researchers to conduct vehicle benchmarking and testing activities that provide data critical to the development and commercialization of next-generation vehicles.

Argonne also serves as the lead laboratory for hardware-in-the-loop (HIL) and technology validation for the U.S. Department of Energy (DOE). Argonne employs HIL techniques to evaluate new technologies and control strategies in an emulated vehicle environment.

The offered testing services and related standards compliance are listed in Table 42 below.

Table 42. Testing capabilities of Argonne's Advanced Powertrain Research Facility

Testing services/capabilities	Related standards compliance
PHEV	
PHEV performance and efficiency testing - Battery cycles testing - Electrical energy consumption	SAE J1711 - Recommended practice for measuring the exhaust emissions and fuel economy of hybrid-electric vehicles, including plug-in hybrid vehicles
PHEV emissions testing	SAE J1711 - Recommended practice for measuring the exhaust emissions and fuel economy of hybrid-electric vehicles, including plug-in hybrid vehicles
Conductive charge coupler testing for PHEV	SAE J1772 - SAE electric vehicle and plug in hybrid electric vehicle conductive charge coupler
EV	
EV – electric grid communication	SAE J2847 Communication between plug-in vehicles and the utility grid
Conductive charge coupler testing for EV	SAE J1772 - SAE electric vehicle and plug in hybrid electric vehicle conductive charge coupler
Dynamometer testing EV	SAE J1634 - Electric vehicle energy consumption and range test procedure
Dynamic modelling and simulation	SAE Jxxx , advanced research[1]

Argonne engineers chair a Society of Automotive Engineers (SAE) committee dedicated to determining test procedures for establishing fuel economy estimates for PHEVs. The committee works to update the existing hybrid test procedure (SAE J1711) to incorporate a consistent and practical approach to evaluating PHEVs. The updated J1711 test procedure is now the industry-wide recommended practice for testing the fuel economy and electrical energy consumption for PHEVs.

More information on the research activities and related testing services and capabilities can be found by following this link: http://www.anl.gov/energy/transportation.

[1] The „advanced research" term refers to laboratory testing which is not being performed according to a specific standard, but meant as pre-standardization work on a specific topic (this involves afferent research and development activities).

An overview on the Advanced Powertrain Research Facility equipment is offered here: http://www.transportation.anl.gov/D3/pdfs/ANL_APRF_DynoTestingReference_July2013.pdf and here: http://www.transportation.anl.gov/facilities/4WD_testcell.html.

10.2.1.2 **Idaho National Laboratory (US)**

The Idaho National Laboratory (INL) is conducting this work with various electric utility and manufacturing partners, as well as the Advanced Vehicle Testing Activity (AVTA) testing partner ECOtality (a provider of electric transportation and storage technologies). The AVTA is tasked by the U.S. Department of Energy's (DOE) Vehicle Technologies Office (VTO) to conduct various types of charging infrastructure testing and demonstration activities.

The Electric Vehicle Supply Equipment (EVSE) testing activities have historically included low to high power energy transfers from the electric grid and distributed energy sources to plug-in electric drive vehicles. The equipment testing includes wire-to-wire conductive energy transfer as well as wireless energy transfer capabilities.

The offered testing services and related standards compliance are listed in Table 43.

Table 43. Testing capabilities of INL Research Facility

Testing services/capabilities	Related standards compliance
PHEV & EREV	
Accelerated on-road and baseline performance (dynamometer and test track)	advanced research
On-road data collection for benchmarking the vehicle and charging profiles in real-world applications	advanced research
Electric Drive and Advanced Battery and Components Testbed (EDAB): capture real world performance, capacity characteristics, and operating conditions of the subject ESS	advanced research
EVSE	
Wireless Charger Testing	SAE J2954 - Establishes minimum performance and safety criteria for wireless charging of electric and plug-in vehicles
AC Conductive EVSE Testing	SAE J1772 - SAE electric vehicle and plug in hybrid electric vehicle conductive charge coupler
DC Conductive EVSE Testing	CHAdeMO Standard - DC fast charging standard- final drafts IEC 61851-23 for charging system, 61851-24 for communication; and IEC 62196-3 for connector
Bi-directional energy transfer technologies for fast charger to support/ offset peak building loads (V2G)	advanced research
DC Fast Charge for Battery Energy Storage (DCFC-BES)	advanced research

INL and testing partner Intertek also conduct Plug-in Hybrid Electric Vehicle (PHEV) and Extended Range Electric Vehicle (EREV) testing as part of their conduct of DOE's Advanced Vehicle Testing Activity.

More information on the research activities and related testing services and capabilities can be found by following this link:

EVSE: http://avt.inel.gov/evse.shtml

PHEV/EREV: http://avt.inel.gov/phev.shtml

Vehicle batteries: http://avt.inel.gov/energystoragetesting.shtml

10.2.1.3 National Renewable Energy Laboratory (NREL) (US)

The National Renewable Energy Laboratory (NREL) is the U.S. Department of Energy's primary national laboratory for renewable energy and energy efficiency research and development.

NREL's Electric Vehicle Grid Integration Team develops strategies and models to support the development of transportation electrification and the expansion of renewable generation.

At NREL's Vehicle Testing and Integration Facility (VTIF), researchers collaborate with automakers, charging station manufacturers, utilities and fleet operators to assess charging, communication and control technology, and modify PEVs to play an active role in building and grid management.

The offered testing services and related standards compliance are listed in Table 44.

Table 44. Testing capabilities of NREL's VTIF

Testing services/capabilities	Related standards compliance
EV	
Bi-directional energy management of PEVs testing	advanced research
Light- and heavy-duty vehicle climate control load reduction testing	advanced research
Thermal testing of up to six Class 8 trucks	advanced research
EVSE	
Public fast charging testing	advanced research
Wireless drive-on vehicle charging	advanced research
Simultaneous charging of multiple EVs	advanced research
Charging control testing via ethernet, WiFi, WiMax, ZigBee, USB, satellite, RFID, ModBus, smartphone and serial connections	advanced research
EVSE testing and verification - Assess response of PEVs and EVSEs to grid communications	advanced research

More information on the research activities and related testing services and capabilities can be found by following this link: http://www.nrel.gov/vehiclesandfuels/project_ev_grid_integration.html.

An overview on the VTIF equipment is offered here: http://www.nrel.gov/vehiclesandfuels/pdfs/53297.pdf.

10.2.1.4 **Fraunhofer (DE)**

The Fraunhofer Society (Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e. V.) is a German research organization with 67 institutes spread throughout Germany, each focusing on different fields of applied science.

On EV related research activities, 33 Fraunhofer institutes are cooperating closely to promote the development of electric vehicles, focusing not just on the drive concepts, but also on the specification for solar-powered charging stations, and the kind of challenges that lie ahead in terms of power supply and urban planning.

The offered testing services and related standards compliance are listed in Table 45.

Table 45. Testing capabilities of Fraunhofer Research Facility

Testing services/capabilities	**Related standards compliance**
EV	
Dynamometer in climate chamber to examine and optimize the regenerative breaking	Advanced research
Safety test for battery	EUCAR-Level 7 - European Council for Automotive R&D - Hazard Levels and Description of Li-Ion battery systems
Design and testing the electric drive train (electric motor and traction battery as well as multi-motor concepts)	Advanced research
Life cycle test for EV: Tests on the charging cycles of electrochemical storage systems (also climate-controlled)	Advanced research:
Acoustic Lab for automotive	ISO 3745 - Acoustics -- Determination of sound power levels of noise sources using sound pressure -- Precision methods for anechoic and hemi-anechoic rooms
Motor test bench for axial and traction drives as well as wheel hub motor	Advanced research
EMC Test for EV	Advanced research
EVSE	
Smart Grid Lab with grid simulator and virtual batteries for Bi-directional energy transfer technologies (V2G)	Advanced research IEC 61850-series - Communication networks and systems in substations EN ISO/IEC 17025 - accredited laboratory
Conductive and Inductive chargers	Advanced research: IEC15118 - Road vehicles - Vehicle to grid communication interface

	IEC62196 - Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles IEC61851 - Electric vehicle conductive charging system
EVSE-protocol tester	IEC 15118 - Road vehicles - Vehicle to grid communication interface
Grid integration of electric vehicles (V2G)	Advanced research: IEC 61850-series - Communication networks and systems in substations OCPP – Open Charge Point Protocol - an application protocol for communication between EV charging stations and a central management system OCHP - Open Clearing House Protocol - an application protocol for communication between EV and charging station networks as well as market actor
Life cycles test for EVSE Tests on the charging cycles of EVSE equipment (also climate-controlled)	Advanced research
EMC Test for EVSE	Advanced research

Fraunhofer has launched “Forum Elektromobilität e. V.”, an association of about 30 partners from industry and science to further electro-mobility in Germany, plays an important role in this context, serving as a networking platform for its members as well as a hub for new technologies and approaches. Within joint research project “FSEM II” (running from 2013 to 2015), 16 different Fraunhofer institutes are pooling their expertise. The research focuses on a clearly defined range of applications for electro mobility. Project activities are grouped in three clusters: “Drivetrain / Chassis”, “Battery / Range Extender”, and “Body / Infrastructure”.

More information on the research activities and related testing services and capabilities can be found by following this link: http://www.elektromobilitaet.fraunhofer.de/

10.2.1.5 **DTU (Technical University of Denmark) (DK)**

The Technical University of Denmark (Danish: Danmarks Tekniske Universitet) is a university in Kongens Lyngby, just north of Copenhagen, Denmark. There are 2 testing infrastructures related to research activities: SYSLAB and NEVIC.

SYSLAB is a true distributed microgrid and a flexible, intelligent energy laboratory. SYSLAB is used for research and testing of control concepts and strategies for distributed power systems with distributed control. PowerlabDK is an experimental platform for electric power and energy ranging from flexible fundamental research and test laboratories to large-scale experimental facilities and a complete full-scale power distribution system. www.powerlab.dk

The NEVIC test center is located at DTU/CEE and performs interoperability test services for electric vehicles, charging-posts, plugs and cables. The equipment is tested to and beyond the limits of the standards and pre-standards. The facilities of NEVIC give wide flexibility to test whether equipment interacts properly with equipment from other vendors or

service operators. Tests are performed both under normal and extraordinary conditions imposed by the power system.

The offered testing services and related standards compliance are listed in Table 46.

Table 46. Testing capabilities of DTU Research Facility

Testing services/capabilities	Related standards compliance
EV	
Prototype of EV - The eBOX is the first of its kind in Europe. It comes with a large Battery Pack (35 kWh / Up to 240 km), support of bi-directional charging (Vehicle-To-Grid) and a set of advanced computers combined with modern communication protocols and standards	Advanced research
EVSE	
Micro-grid Lab (SYSLAB) - testing and control concepts and strategies for distributed power system as well V2G activities	Advanced research: IEC 61850 series - Communication networks and systems in substations
EV-Simulator, Cable Simulator, EVSE-Simulator, Loads Conductive Charger	IEC 15118 - Road vehicles - Vehicle to grid communication interface IEC 61851 - Electric vehicle conductive charging system OCPP - Open Charge Point Protocol - an application protocol for communication between EV charging stations and a central management system SAE1772 - SAE electric vehicle and plug in hybrid electric vehicle conductive charge coupler
Interoperability test for connectors	IEC 62196-2 - Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles SAE1772 - SAE electric vehicle and plug in hybrid electric vehicle conductive charge coupler
Electric Vehicle Supply Equipment (EVSE) / Charging spot - a series of measuring and computing units that will grant outside control of the charging process. This asset can be used for communication and standardization studies.	Advanced research
Table-To-Grid (T2G) - EV Battery Test Bed - To reproduce the realistic charging or discharging behavior of an EV. The EV test bed can either charge or enter the Vehicle-to-Grid mode, using a flexible communication and control architecture, using contemporary communication standards. In addition, the test bed is	Advanced research

designed for electrical and thermal characterization studies.	

More information on the research activities and related testing services and capabilities can be found by following this link:

SYSLab: www.powerlab.dk/facilities/SYSLAB

NEVIC: www.powerlab.dk/Facilities/NEVIC

10.2.1.6 **Austrian Institute of Technology (AIT) (AT)**

The development of new vehicle concepts necessitates detailed information about the electrical, thermal and mechanical characteristics of individual components and entire drives. Thanks to a sophisticated laboratory infrastructure, the Energy and Mobility Departments are able to provide these data for all relevant components – from electrical machines and power electronics to electric energy storage systems and entire vehicles. The Department also specialises in combining measuring techniques with simulation for demanding Hardware-in-the-Loop tests.

The offered testing services and related standards compliance are listed in table below.

Table 47. Testing capabilities of AIT Research Facility

Testing services/capabilities	**Related standards compliance**
EV	
Dynamic inverter test rigs - allow for the variable feed of frequency and voltage and cover a broad spectrum – from small drives for auxiliary equipment to drive motors for electric and hybrid vehicles.	Advanced research
Motor test bench to characterise the electric machines with regard to engine speed and torque	Advanced research
Characterisation of vehicles in relation to power requirement under different driving conditions	Advanced research
Electrical, mechanical and thermal measurements on the road (Real Life Cycle Tests) and on the roller test bench	Advanced research
Special drive testing (e.g. start procedures for starter generator systems; coupling of electric machine with mechanical appliance, etc.)	Advanced research
Battery as well as cell characterisation - measurement and performance profile under defined environmental conditions	Advanced research
Stress Test for batteries - High-current/high-voltage testing of batteries for automotive applications including Misuse tests: behaviour of batteries under extreme electrical, mechanical and thermal loads or	Advanced research

overload	
Life cycle of batteries - Environmental simulations including temperature, pressure, vibration, weathering as well as endurance and ageing tests during storage or cycling in increased temperatures	Advanced research
Reliability, quality and safety - On a day-to-day basis, technical devices are required to meet very high standards, especially in extreme climatic conditions.	Advanced research
Modelling, Simulation and Library Development of Electric Drives and Vehicles	Advanced research
EVSE	
Smart-Grid Lab for bi-directional energy transfer technologies (V2G)	Advanced research IEC61850 series - Communication networks and systems in substations
Design and Prototyping of Electric Components	Advanced research
Error analysis of power electronics components	Advanced research

More information on the research activities and related testing services and capabilities can be found by following this link:

http://www.ait.ac.at/research-services/research-services-mobility/testing-and-validation-of-electric-components/?L=1

http://www.der-lab.net/derlabsearch/repository/AIT/dbfacilities/docs/EDT-Profilfolder_Mai11_en_lowres.pdf

10.2.1.7 **RSE SpA (Ricerca sul Sistema Energetico) (IT)**

RSE SpA, is a joint stock company, whose unique shareholder is GSE SpA, which develops research in electro-energy. RSE activities in this area cover, with a multidisciplinary approach, the entire range of issues that concern the impact of electric mobility on the national network: from the analysis of different electric mobility scenarios to the evaluation of the influence of electric and hybrid vehicles on local and national air quality; from the development and application of methods to predict the impact on the electricity distribution network, to the evaluation of regulatory implications and social acceptability, etc.

The offered testing services and related standards compliance are listed in table below.

Table 48. Testing capabilities of RSE SpA Research Facility

Testing services/capabilities	Related standards compliance
EV	
Characterisation of energy storage systems in terms of performance and life cycle as well as testing in climate chamber	Advance research
EVSE	
Smart-grid lab for the evaluation of hosting capacity and dynamic grid behaviour.	Advance research: IEC 61850-series - Communication networks

Experiments deal with technological aspects: interoperability; control and communication issues of V2G services.	and systems in substations
Conductive chargers	IEC 61851 - Electric vehicle conductive charging system IEC 62196-2 - Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles

More information on the research activities and related testing services and capabilities can be found by following this link:

http://www.rse-web.it/temi/sottotema/9?objId=3

10.2.1.8 **TECNALIA Research & & Innovation (Tecnalia) (ES)**

TECNALIA complements the research vocation with accredited testing capabilities to measure and assess the compliance of products to Standards and Regulation. This brings the opportunity for TECNALIA to become an active stakeholder to offer the OEMs, the charging point manufacturers, the utilities, the E-mobility service providers and, in general, the companies around the EV charging, the infrastructure, capability and knowledge to verify that their systems perform as desired.

TECNALIA has an advanced platform for characterising, developing and validating mechanical and electrical components which can be combined with high performance electric vehicles. TECNALIA especially focuses on EV integration within the smart grid, BMS development, test benches, business models analysis, fast charge and other advanced power electronics based systems. Further fields of research include tele-management as well as data collection systems (EVSE, EVSP, DSO). For wireless charging TECNALIA has developed a system based on a resonant magnetic coupling, able to charge an EV at 3.3 kW with a performance above 93%.

The offered testing services and related standards compliance are listed in table below.

Table 49. Testing capabilities of Technalia Research Facility

Testing services/capabilities	**Related standards compliance**
EV	
Characterisation of energy storage systems in terms of performance and life cycle as well as testing in climate chamber UV aging chamber, temperature and humidity cycling, and salt spray	Advance research
Vehicle dynamic model interacts with the driver and physical hardware at the same time with deterministic performance.	Advance research
Advanced platform to characterise, develop and validate mechanical and electrical components for EV	Advanced research
EVSE	
Smart-grid lab for the evaluation of hosting	Advance research:

capacity and dynamic grid behaviour. Experiments deal with technological aspects: interoperability; control and communication issues of V2G services.	IEC 61850-series - Communication networks and systems in substations EN ISO/IEC 17025 - accredited laboratory
Conductive chargers	IEC 15118 - Road vehicles - vehicle to grid communication interface IEC 61851 - Electric vehicle conductive charging system
Low voltage switchgear and control gear assembles, also for EV	EN 61439-7 - Low-voltage switchgear and control gear assemblies - Part 7: Assemblies for specific installations at public sites such as marinas, camping sites, market squares and similar applications and for charging stations for electrical vehicles
Wireless charge development	Advanced research

More information on the research activities and related testing services and capabilities can be found by following this link: http://www.tecnalia.com/en/energy-environment/infrastructure-a-equipment/infrastructure-a-equipment.htm, http://www.dynacar.es/en/technical-characteristics.php

10.1.1.1 Politechnika Lodzka – Lodz University of Technology (TUL) (PL)

Laboratory of Distributed Generation serves for testing the integration of distributed generation with the power networks. This facility is designed to build, simulate and test microgrids (including EV charging stations) and its interoperability with power networks. Furthermore it can serve to evaluate immunity to disturbances and the energy management strategies of the EV charging stations connected to grids with RES.

The laboratory consists of Real Time Digital Simulator with EmTest multifunctional power source with power recovery module, flywheel, supercapacitors and battery energy storage devices, PV panels, wind generators, fuel cell systems, gas microturbine and controllable loads

The offered testing services and related standards compliance are listed in table below.

Table 50. Testing capabilities of TUL Research Facility

Testing services/capabilities	Related standards compliance
EVSE	
EMC and power quality test for EVSE under laboratory of distributed generation	Advance research:

More information on the research activities and related testing services and capabilities can be found by following this link:

http://www.dispower.org

10.2.1.9 Hori-Fujimoto Laboratory - University Tokyo & Yokohama National University (JP)

Hori Lab (from the Institute of Industrial Science, the University of Tokyo) and Fujimoto Lab (from Yokohama National University) were combined into Hori-Fujimoto Lab in April 2011. Therefore, there will be no difference whatsoever in being assigned as a Hori Lab member or a Fujimoto Lab member.

The fields of research we are handling are as follows: control theory and its practical use, digital control, motion control, robotics, electric vehicles, wireless power transfer, power electronics, and electric airplanes.

The offered testing services and related standards compliance are listed in table below.

Table 51. Testing capabilities of Fraunhofer Research Facility

Testing services/capabilities	Related standards compliance
EV	
Control system technology for electric motor to stable steering for electric motor on low friction road	Advanced research
Development of in-wheel motors - control algorithms for wheel to be driven independently to improve the stability of driving control	Advanced research
EVSE	
Development of wireless power transfer technology based on Electromagnetic Resonance Coupling	Advance research

More information on the research activities and related testing services and capabilities can be found by following this link: http://hflab.k.u-tokyo.ac.jp/index.html

10.2.1.10 Japan Automobile Research Institute (JARI) (JP)

Japan Automobile Research Institute (JARI), established through the reorganization of the former Automobile High - Speed Proving Ground Foundation in April 1969, engages in general research on automobiles. It started as a public - service corporation of a test - research organization intended to contribute to healthy development of the automotive society. It has since progressed with the development of automobiles in Japan.

JARI continues research into EV test methods and testing equipment to ensure fair, accurate assessment of EV fuel economy. Further, we are involved in the establishment of a global hardware-in-the-loop simulator method of testing HEV emission and fuel economy performances by calculating the engine speed and torque.

The offered testing services and related standards compliance are listed in table below.

Table 52. Testing capabilities of JARI Research Facility

Testing services/capabilities	Related standards compliance
EV	

Chassis dynamometers - basic performance tests on EVs including the tests on the fuel economy of EVs, HEVs, PHEVs and FCVs	Advanced research
Anti-explosion fire testing	Advanced research
Global hardware-in-the-loop simulator method of testing HEV emission and fuel economy performances including regenerative braking	Advanced research
charge-discharge and deterioration-durability performances of batteries: test resistance to weather, heat, impact, perforation and crush is put to use at Hy-SEF in order to assess the safety performances of batteries	Advanced research
Fuel cell performance assessment: fabricates and assesses membrane electrode assemblies, and conducts experiments to determine the effect of impurities contained in hydrogen fuel.	Advanced research
Safety specifications - Electrically propelled road vehicles	ISO 6469 - Electrically propelled road vehicles - Safety specifications (Part 1: On-board rechargeable energy storage system (RESS))
Hydrogen consumption measurement for FCV	ISO 23828 - Fuel cell road vehicles. Energy consumption measurement. Vehicles fuelled with compressed hydrogen
Standard on automotive hydrogen fuel properties for FCV	ISO 14687-2 - Hydrogen fuel. Product specification. Proton exchange membrane (PEM) fuel cell applications for road vehicles
Standards for hydrogen connectors and high-pressure hydrogen tanks for FCV	ISO 17268 - Compressed hydrogen surface vehicle refuelling connection devices
Emissions and fuel economy measurement methods for HEVs with or without external charging	ISO 23274-1, ISO 23274-2 - Hybrid-electric road vehicles -- Exhaust emissions and fuel consumption measurements - part 1: Non-externally chargeable vehicles and part 2: Externally chargeable vehicles
Battery performance testing	IEC 62660-1, - 2- Secondary lithium-ion cells for the propulsion of electric road vehicles - part 1: Performance testing, part 2: Reliability and abuse testing
Electrical characteristic of double layer capacitor for hybrid electric vehicles	IEC 62576 - Electric double-layer capacitors for use in hybrid electric vehicles - Test methods for electrical characteristics
EVSE	
Investigation into AC standard charger feasibility - charging failure due to feasibility problems between vehicles and chargers.	Advanced research
Interoperability test for connectors	IEC 62196 - Plugs, socket-outlets, vehicle couplers and vehicle inlets - Conductive charging of electric vehicles

As Japanese deliberation body working with ISO/TC22 (Road vehicles), ISO/SC21 (Electrically propelled road vehicles) and IEC/TC69 (EVs and electric industrial vehicles),

JARI carries out drafting and commenting concerning ISO and IEC standards and Japanese JIS standards for EVs, hybrid electric vehicles (HEVs) and fuel cell vehicles (FCVs), and is also involved in standardization discussions at ISO/TC197 (hydrogen technology), IEC/TC21 (batteries), and IEC/SC23H (industrial plug and socket-outlets) in concert with associated organizations.

More information on the research activities and related testing services and capabilities can be found by following this link:

http://www.jari.or.jp/tabid/216/Default.aspx

Other Japanese EV related standard can also be found by following link below:

http://www.evaap.org/pdf/jevs.pdf

10.2.1.11 Others research activities in Asia

The Electric Vehicle Association of Asia Pacific (EVAAP) is an international membership organization founded in 1990, acting to promote the development and use of electric and hybrid vehicles in Asia and Pacific region. Up to the moment of writing this report, members from Japan, Korea, China, Hongkong and Singapore have joined this organisation. EVAAP is the Asian-Pacific representative for the World Electric Vehicle Association (WEVA), organizing the International Electric Vehicle Symposium (EVS) rotationally with AVERE (Association for Battery, Hybrid and Fuel Cell Electric Vehicles) and EDTA (Electric Drive Transportation Association).

To achieve its purpose, EVAAP will:

- Encourage and facilitate the exchange of relevant information among its members and with international organizations with similar purpose;
- Collaborate and cooperate with other international bodies in activities of similar purpose;
- Represent its membership in the World Electric Vehicle Association (WEVA);
- Endeavour to act as a source of relevant information for public dissemination, educational and government bodies, and;
- Conduct any other activities deemed fit and proper for the accomplishment of its overall purpose.

More information on the research activities and related testing services and capabilities can be found by following this link: http://www.evaap.org/

10.2.2 International certification bodies

10.2.2.1 UL (Underwriters Laboratories, Inc.)

UL is the key North American developer of safety-related EV Standards. We also actively cooperate with other standards developing organizations in sharing our EV safety expertise.

EV charging systems require safe installations and safe integration with household systems to protect consumers and their household data and to prevent electrical fires, short-outs, power surges and power leakages. UL has the knowledge and experience to help you differentiate your products by testing next-generation components and certifying that they're compliant with the National Electrical Code® (NEC)

The Underwriters Laboratories, Inc. (UL) is a global independent safety science company. UL provides safety design and testing standards across several industries. Several standards apply directly to the design of electric vehicles, including the cords, cables, connectors, and traction motors. The following standards are specifically noted.

The offered testing services and related standards compliance are listed in table below.

Table 53. Testing capabilities of UL Research Facility

Testing services/capabilities	Related standards compliance
EV	
Safety for Rotating Electrical Machines - General Requirements	UL 1004-1
Safety of Power Converters/Inverters for Electric Land Vehicles	UL 458A
Safety of Electric Vehicle (EV) Charging System Equipment	UL 2202
Standard for Batteries for Use in Electric Vehicles	UL 2580
EVSE	
Electric Vehicle Charging System Equipment	UL 2202
Personnel Protection Systems for Electric Vehicle Supply Circuits	UL 2231-1 and 2231-2
Plugs, Receptacles, and Couplers for Electric Vehicles	UL 2251
Batteries for Use in Electric Vehicles	UL 2580
Power Converters/Inverters for Electric Land Vehicles	UL 458A
Electric Vehicle Supply Equipment	UL2594

More information on the research activities and related testing services and capabilities can be found by following this link:

EVSE-standards:
http://www.ul.com/global/documents/offerings/industries/powerandcontrols/resources/EV_Connecting_to_EV_Infrastructure_us_final.pdf

On-board & off-board standards:

http://www.ul.com/global/eng/pages/offerings/industries/powerandcontrols/electricvehicle/evstandards/

10.2.2.2 **INTERTEK**

Intertek has made significant investments in alignment with the evolving needs of your business. We offer lab capacity for EV, HEV, PHEV and automotive battery testing services on a global scale to certify your charging stations and electrical components for worldwide distribution.

The offered testing services and related standards compliance are listed in table below.

Table 54. Testing capabilities of INTERTEK Research Facility

Testing services/capabilities	**Related standards compliance**
EV	
Battery Testing	UL 1642, UL 2054, UL 2271, UL 2580 IEC/EN 62133
Secondary lithium-ion cells for the propulsion of electric road vehicles	IEC 62660 series
Electrically propelled road vehicles -- Test specification for lithium-ion traction battery packs and systems	ISO 12405 series
Electrical characteristics and electrical safety of high voltage components in road vehicles	LV 123
Electric Vehicle Testing	SAE J1772, SAE J2464
Electric Vehicle Battery Testing	IEC 60086-1, 60086-2, 60086-3
CTIA Accredited Battery Testing	IEEE 1725, IEEE 1625
Failure Analysis and Battery Safety Investigations	advanced research
Nordic Ecolabel Testing (White Swan)	advance research
Electrochemical Storage System Abuse Test Procedure Manual Requirements	SAND 99-0497 (Sandia-Lab)
Transportation Testing for Lithium Batteries	UN/DOT 38.3, IEC 62228
Functional Safety of Electrical/Electronic /Programmable Electronic Safety-related Systems	UL 1998, ISO 26262 series
EMC	ECE-R 10, ECE-R-100
EVSE	
On-Board Battery Chargers	SAE J2894, UL 2202 IEC 61851
Charging Inlet	SAE J1772, UL 2251 CHAdeMO IEC 62196
Testing of electrical connectors	LV 214
Charging Station/Cordsets	SAE J2293, UL Subject 2594 IEC/EN 61851 series
DC Quick Chargers	SAE J1772, UL 2202 CHAdeMO IEC 61851
Charging Plug	SAE J1772, UL 2251 CHAdeMO IEC/EN 62196 series
Personnel Protection Circuitry	UL 2231-1/-2, CSA 22.2#281.1/.2

	IEC 61540, IEC 62752, IEC 61008, IEC 61009
Functional Safety of Electrical/Electronic /Programmable Electronic Safety-related Systems	UL 1998, UL 991 IEC 61508
EMC	FCC Part 15, FCC Part 18 EMC directive 2004/1008/EC IEC/EN 61000-6 series Intentional radiators based on ETSI/EN standard

As unquestioned global leaders in EVSE testing and certification, our engineers help you plan for market conformance and avoid delays. Drive your electric vehicle chargers and EV-related systems and components to market faster with integrated safety, performance and interoperability testing to all industry-recognized SAE, UL, IEC and EN standards, as well as local and regional regulatory requirements.

More information on the research activities and related testing services and capabilities can be found by following this link:

Vehicle Battery Certification and Safety Testing:

http://www.intertek.com/automotive/electric-vehicle/battery-certification/

Electric Vehicle Supply Equipment Testing & Certification:

http://www.intertek.com/automotive/electric-vehicle/evse/

http://www.intertek.com/uploadedFiles/Intertek/Divisions/Commercial_and_Electrical/Media/PDF/Battery/Electric-Vehicle-Supply-Equipment-EVSE-Certification.pdf

10.2.2.3 **TÜV-SüD (DE)**

Electric drives will play an increasingly important role in future automotive powertrain technology – either as auxiliary drive motors in hybrid electric vehicles (HEV) or as sole propulsion systems in battery electric vehicles (BEV). Developers are entering new territory here which requires them to deal with new components and new testing procedures as well as new safety risks. TÜV SÜD Automotive supports you in this endeavor – with a comprehensive range of E-mobility training, consulting and testing services.

TÜV SÜD Automotive supports you in developing your hybrid electric and battery electric powertrains with a comprehensive portfolio of services – from project consulting and employee training to analytics as well as testing and certification of your components, systems and vehicles.

- In the field of Electrical Safety, you can draw on our complete range of testing and certification services for high-voltage systems and benefit from the diverse experience of our experts.
- Functional Safety plays a crucial role with hybrid electric and battery electric powertrains. As an accredited testing authority, we assist you in reducing existing risks. Since we are an organization that is involved in defining industry norms we are intimately familiar with all applicable standards – such as ISO 26262.

- The evaluation of Chemical Safety represents a new field regarding the safety requirements to be met by electric vehicles, particularly with respect to batteries (flammable/harmful substances, risks of the electrolyte).
- In addition, our specialists ensure the Mechanical Safety of electric vehicles. Relevant tests include, among other things, quasi-static or dynamic battery tests. These tests are required for lithium-ion batteries in particular.

The offered testing services and related standards compliance are listed in table below.

Table 55. Testing capabilities of AIT Research Facility

Testing services/capabilities	Related standards compliance
EV	
FreedomCAR Battery Test Manual For Power-Assist Hybrid Electric Vehicles	DOE/ID-11069
FreedomCAR Ultracapacitor Test Manual	DOE/ID-11173
Secondary lithium-ion cells for the propulsion of electric road vehicles	IEC 62660-1/2
Secondary cells and batteries containing alkaline or other non-acid electrolytes - Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications	IEC 62113
Electrically propelled road vehicles. Test specification for lithium-ion traction battery packs and systems. High-power applications	ISO 12405-1/2
EV & HEV Rechargeable Energy Storage System (RESS) Safety and Abuse Testing Procedure	SAE J2464
FreedomCAR - Electrical Energy Storage System Abuse Test Manual for Electric and Hybrid Electric Vehicle Applications (Sandia-Lab)	SAND2005-3123
Lithium Battery Transport Tests & UL Battery Safety	UN 38.3, SBA S1101
EVSE	
Electrical safety for charging plug & inlet	IEC 62196, SAE 1772
Electrical safety for charging station	IEC 61851, IEC 60950, UL 60950, SAE J2293

Accredited experts from TÜV SÜD Automotive will help you to obtain approval for your vehicle – from two-wheeled vehicles, quads and passenger cars all the way to heavy commercial vehicles. Tests are based on:

1. 2007/46/EC and 2002/24/EC
2. ECE R 100
3. StVZO (German Road Vehicle Registration Regulation)

More information on the research activities and related testing services and capabilities can be found by following this link:

http://www.tuev-sued.de/automotive/e-mobility

http://www.tuev-sued.de/uploads/images/1368759083901602300490/tuv-sud-realise-the-potential-of-e-mobility.pdf

10.2.2.4 **MET labs (US)**

MET Labs is experienced testing within the growing industry of electric vehicles and electric vehicle charging stations (EVSE), having tested the all-electric Tesla at MET's Santa Clara, CA facility in Silicon Valley. MET has also tested and certified EV charging stations from a number of different manufacturers. MET Labs is also an active tester of Lead Acid, Lithium-based, Zinc-air, Aluminum-air, Sodium Sulfur, & Nickel-based batteries.

The offered testing services and related standards compliance are listed in table below.

Table 56. Testing capabilities of MET Labs Research Facility

Testing services/capabilities	**Related standards compliance**
EV	
on Board Vehicles, Boats, and on Devices	CISPR 25 - Radio disturbance characteristics for the protection of receivers used on board vehicles, boats, and on devices
Environmental Testing	IEC 60068-2-11 - Environmental testing - salt mist
EMC	IEC 61000-4-4 - Electrical fast transient/ burst immunity test IEC 61000-4-5 - Surge test ISO 10605 - ESD immunity ISO 11452-2 - Radiated immunity ISO 11452-4 - Conducted immunity
Electrical Disturbances from Conduction and Coupling - Electrical Transient	ISO 7637-2, -3: - Road vehicles - Electrical disturbances from conduction and coupling – part 2 - electrical transient - conduction along supply lines only, part 3 - Transmission by capacitive and inductive coupling via lines other than supply line
EVSE	
General Use Power Supplies	CSA 22.2 No. 107.1-01 - General use power supplies
EMC	FCC Part 15.107 - Conducted emissions FCC Part 15.109 - Radiated emissions FCC Part 15.203 - Antenna requirements FCC Part 15.207 - Conducted emissions FCC Part 15.225 (a) - Field strength of fundamental emission FCC Part 15.225 (b,c,d) - Field strength of spurious emissions
EV Power Outlets, EV cord sets and EV	UL Subject 2594 - Electric vehicle supply

charging stations,	equipment
Personal protection	UL2231—1, 2 - Personnel protection systems for electric vehicle (EV) supply circuits: Part 1 - General requirements, Part 2 - Particular requirements for protection devices for use in charging system
Electric Vehicle (EV) Charging System Equipment	UL2202 - Electric Vehicle (EV) charging system equipment
Enclosures for Electrical Equipment	NEMA 250-2003 - Enclosures for electrical equipment (1000 Volts maximum)
Personal communication services	FCC Part 24 - Personal communication services RSS-133 - 2 GHz Personal communication services
Communication on physical layer	FCC Part 15.225 (e) - Frequency stability FCC Part 22 - Public mobile services ICES-003 - Digital apparatus RSS-132 - Cellular telephones employing new technologies operating in the bands 824-849 MHz and 869-894 MHz. RSS-210 - License-Exempt radio apparatus (all frequency bands): category I equipment
Lithium Batteries	UL 1642 Safety of lithium batteries SAE J2380 Vibration testing of electric vehicle batteries GR-3150-CORE Generic requirements for secondary non-aqueous lithium batteries GR-4228-CORE VRLA battery string certification levels based on requirements for safety and performance VZ.TPR.9802 Valve regulated lead acid (VRLA) battery qualification test requirements IEC 62133 Safety of lithium ion batteries UN/DOT 38.3 Transportation testing for lithium batteries

More information on the research activities and related testing services and capabilities can be found by following this link:

Electric vehicle: http://www.metlabs.com/Industries/Automotive/Electric-Vehicles.aspx

Battery: http://www.metlabs.com/Industries/Battery.aspx

10.2.3 Further EV and EVSE related testing infrastructure available within the DERlab network

European Distributed Energy Resources Laboratories DERlab is the association of leading laboratories and research institutes in the field of distributed energy resources equipment and systems and currently has 27 member institutes in Europe and the US. Many of the member laboratories have reinforced their capabilities in recent years for assessing

compliance for EV, EVSE, Smart Charging and V2G and also towards the validation of systems against different standards. Table 57 presents different DERlab member institutes that have research capabilities for testing EV interoperability. Some of the members are also the COTEVOS project partners.

Table 57 DERlab member organisations having EV, EVSE, Smart Charging or V2G research and testing facilities

Organisation	Country
Austrian Institute of Technology (AIT)	Austria
Centre for Renewable Energy Resources and Savings (CRES)	Greece
DNV GL Energy	Germany
DTU Electrical Engineering	Denmark
EDF – R&D / Concept Grid	France
ENEL Ingegneria e Ricerca S.p.A.	Italy
EnergyVille / VITO / KULeuven	Belgium
Fraunhofer IWES	Germany
French National Institute for Solar Energy (INES) at CEA	France
Grenoble Electrical Engineering laboratory	France
HES-SO Valais, School of Engineering	Switzerland
INESC PORTO	Portugal
Lodz University of Technology	Poland
National Renewable Energy Laboratory (NREL)	USA
National Technical University of Athens, Institute of Communication and Computer Systems	Greece
Research Centre for Sustainable Energy FOSS	Cyprus
Ricerca sul Sitema Energetico - RSE S.p.A.	Italy
Sandia National Laboratories	USA
TECNALIA Research and Innovation	Spain
University of Luxembourg	Luxembourg
University of Strathclyde	UK
VTT Technical Research Centre of Finland	Finland

The DERlab database of DER and Smart Grid Research Infrastructure provides an overview of the testing capabilities of its member institutes (http://www.der-lab.net/derlabsearch/public/index.php).). Furthermore, the database integrates a specific section related to available EV research and testing as shown in Figure 125. This includes the EV testing facilities from COTEVOS participants as well as from external institutes outside the project consortium. (http://www.der-lab.net/derlabsearch/public/search_ev_facilities.php).

Figure 125 Electric Vehicles Research and Testing laboratories

10.2.4 Summary of findings

The analysis of the collected information related to EV and EVSE-relevant testing capabilities as well as related testing infrastructure identifies services/capabilities currently being used for a variety of applications, as summarised below:

- correct sizing of smart charging infrastructure
- development of appropriate EV-EVSE-grid interfaces
    - various standard communication protocol incl. EV- and EVSE emulators
    - physical connection - plugs, receptacles and couplers
- ensuring reliable power supply of EV units in the context of concentrated simultaneous grid connection while maintaining grid stability
- development of V2G concept by integrating virtual batteries at the grid connection point with focus of provision of grid support services
- testing of smart charging stations in terms of climatic related performance, life-time and EMC
- electromagnetic compatibility (EMC) testing of units and systems
- units performance and life cycle tests
    - efficiency and distortion from inverters including errors analysis
    - electric machines with regard to engine speed and torque
    - energy storage system (ESS) with regards to different charging profiles (e.g. high-current/high-voltage testing, misuse tests: behaviour under extreme electrical, mechanical and thermal loads)
    - emission and fuel economy performance incl. regenerative breaking
    - benchmarking the vehicle and charging profiles in real-world applications by on-road data collection
- safety issues
    - electrical related issues: synchronisation, abnormal voltage/frequency, unintended islanding
    - mechanical related issues: fire exposure, transportation
    - personal safety
- EV and EVSE product development (e.g. inductive charger, in-wheel motor control, etc.)
- Conformance test for the connection establishment, interruption and reestablishment

Further to the information collection on existing infrastructure as well as services/capabilities at international level among research institutes and certification bodies, another focus on the analysis has been oriented on supporting the definition of needs and requirements for new testing services and procedures to be implemented within COTEVOS project.

From the research institutes perspective, the research activities are mostly focusing on V2G issues like grid support/services provision and communication protocol testing, as well as EV/EVSE product developments (including performance, reliability and life cycle analysis). The certification bodies' activities and capabilities are mostly focused on safety issues as well as performance, reliability and life cycle tests.

Compared to European and North-American focus of activities, strong research and development efforts are concentrated on fuel cell vehicles (FCV) in Asia. They are also performing research, development and testing on hydrogen connectors (ISO 17268), properties of hydrogen and its storage safety (ISO14687) as well as on hydrogen consumption (ISO 23828).

There are numerous activities world-wide concentrated on further standards development related to interoperability issues which go beyond the interfaces among EV,

EVSE and grid by also integrating system operators, grid users and the electricity market layer.

Concerning the interface between EV and EVSE two solutions can be identified: conductive and inductive interfaces. For conductive charging system, there are research activities on the communication and physical coupler. Regarding communication tests, SAE J2894, SAE J2293, UL 2594 and UL 2202 standards have been implemented in North-America, while IEC61851, IEC 15118 and IEC 61851 standards have been applied for the communication in European market. In Asia, CHAdeMo standard has been employed either for communication or physical coupler. For the physical coupler standards in North-America, SAE J1772, UL 2251 have been used, while IEC 62196 is used in Europe. However, there are efforts among research institutes and certification bodies to provide the different testing capabilities for the North-American, European and Asian markets as well as providing mobile communication testers (e.g. IEC 15118). Currently, Japan is working on harmonizing the CHAdeMO standards within IEC-Standards (e.g. CHAdeMO charging system is now in final drafts of international standards at IEC - IEC 61851-23 for charging system, 61851-24 for communication; and IEC 62196-3 for connector). Regarding inductive charging system, however, there are still many open issues which need further research. The specification of inductive charging system is still under development in Europe and the US (SAE J2954 and IEC 61980).

Regarding the interface between EV/EVSE to the grid and system operator, IEC 61850, SAE J2847, OCPP and OCPP communication are used from different regions of the world. The Interface between EV/EVSE and the grid could be employed with IEC 61859, OCPP and SAE J2847, while the interface between EV/EVSE and backend (e.g. system operator, clearing house) could be done by OCPP. However, the standardized interface between EV/EVSE to backend is still open.

With respect to objective of COTEVOS project, the main available interoperability tests provided by COTEVOS participants are mainly on the paths A, E and G, as defined in “Overview of functions in electro-mobility data communication” Figure 1 and explained hereafter.

Interaction between EV and EVSE (path A)

The physical connector compatibility and signal pin (control pilot and plug direct) between EV and EVSE (defined by IEC 62196 and IEC 61851) could be covered by mobile test equipment from project partners on both AC and DC modes (ranging from charging mode 1-4). At the same time, the communication protocol testers between EV and EVSE (defined in IEC 15118) could also be covered by project partners. The DC quick charging system (e.g. CHAdeMO and SAE J1772) are still under development by some of project partners.

With respect to wireless charging between EV and EVSE, there are many proprietary communication protocols provided by different manufacturers (e.g. Bosch, Qualcomm). Therefore, standards for wireless chargers are needed, which are currently developed under IEC15118 standard.

Interaction between EV/EVSE and the grid (path E, G)

The communication between EVSE and a central management system (known as charging station network), could be tested with OCPP protocol testers. Such testers are still

under development by some of the COTEVOS project partners. At the same time, some of decentralized DER system integration (according to IEC 61850 series) have already been developed under micro-grid activities and tested with power grid testing facilities, which can also be used with EV system integration.

Interaction between EV/EVSE and users information (identification, billing) (path B, C, D)

The communication protocol between EVSE and clearing house units (OCHP) and those related to identification and billing issues are also still under development.

10.3 Further complementary aspects concerning COTEVOS Consortium capabilities versus current world-wide developments

This chapter describes the capabilities of testing facilities within COTEVOS consortium to provide the services to the EV public available infrastructures. Table 58 describes the current state of the art of EV public available infrastructures, emerging needed of EV business field on testing requirement, procedures and related infrastructures and capabilities of testing facilities within COTEVOS and DERlab consortium.

Table 58 Comparison between existing EV infrastructures and testing facilities

Nr.	EV business field (available products and market trends)	Emerging needs of EV business (testing requirements, procedures and infrastructures)	COTEVOS capabilities
1	Commonly used EVs are equipped with only low power on-board chargers. Additionally they are only single – directional technology.	The performance test could be achieved by the power grid testing infrastructures as well as mobile power measurement testing equipment. At the same time, the interoperability test could be achieved by IEC 61851 and IEC 15118.	Available/ Under development[2]
2	There is a plenty of solutions for connectors/inlets and plugs/outlets. However, standardization in this field results with limitation of solution's number that can be taken into account by the manufacturers.	The various physical connectors/inlets and plugs/outlets could be covered by IEC 62196. However, the international standards (CHAdeMO and SAE-J1772) needs to be harmonized and further tested.	Available Under development
3	There are following trends at the EV market: • rising production of fast charging stations (on-board charger is not required), • decrease of fast AC chargers production, • increasing share of usage Combo2 connector in EV, due to availability of both slow AC and fast DC charging. • the ability to set charging duration.	The electrical performance of different charging modes (IEC 61851) could be covered by power grid testing infrastructure, In terms of interoperability test on European level, the physical connectors could be covered by IEC 62196, while the communication protocol could also be covered by IEC 61851 and IEC 15118. With respect to international standard (CHAdeMO and other SAE-series), further development is needed.	Available Available/ Under development Under development

[2] The COTEVOS members could partly cover these IEC-15118 series. Therefore, these IEC-a5118 series are also still under development.

5	Additional requirements regarding functionalities for the entire system will be established, when V2G services are taken into account. In this case: 1) Off-board charger must have the possibility of bidirectional operation, 2) The charger operation should be controlled by the grid operator remotely, therefore communication between EVSE and the grid operator should be established	With respect to V2G services, the performance and bidirectional interaction between EVSE and grid could be tested with power grid testing infrastructures. In terms of interoperability test, the communication between EV/EVSE and grid operator could be achieved by IEC 61850 series, At the same time, the communication between EV/EVSE and charger operator could be achieved by OCPP.	Available Available Under development
6	Only single directional chargers are provided at the market. This does not affect the interoperability level, which is focused more at the EV everyday use, but influences business opportunities for EV systems significantly. One-directional inverter and charger do not allow for V2G services.	In order to provide the V2G services, the bidirectional inverter/charger is needed. This could be developed and further tested on both performance and interoperability issues. The interoperability tests could be covered by IEC 61850 series and OCPP. However, the communication protocol related to market (e.g. billing, user interface) is still open and needs to be harmonized.	Available/ Under development (OCPP) Under development
7	EVSE manufacturers currently support two solutions: slow AC charging and DC fast charging. AC fast charging is not provided yet.	Additional charging modes could also be developed and further tested on both performance and interoperability issues. The interoperability tests could be covered by IEC 61850 series and OCPP.	Available/ Under development (OCPP)

With respect to the available capabilities of testing infrastructures within COTEVOS and DERlab consortium, some testing requirements, procedures and infrastructures are still needed. Therefore, the external partners (i.e. outside COTEVOS) and the DERlab consortium will also be taken into account in order to identify the gaps in EV-related testing infrastructures.

Since COTEVOS consortium has identified excellent research infrastructures also outside of its consortium in Europe and the US and DERlab is an operating agent of Smart Grid International Research Facility Network (SIFRN), part of IEA Smart Grids Action Network (ISGAN), COTEVOS will approach all international testing infrastructures with a proposal for laboratory cooperation.

11 CONCLUSIONS

The e-mobility is still a growing market and therefore new approaches and solutions reflecting the Electric Vehicles (EVs) and the EV Supply Equipment (EVSE) technologies are being continuously introduced. Accordingly, the development of corresponding standards and related test procedures need to keep up the same pace. Both basic and more advanced (intended) functionalities, which are (or: will be) offered to end-user(s), require the interoperability[3] between all involved components. However, in certain cases, e.g. V2G services, the interoperability cannot be always guaranteed. It is recognized that this aspect may eventually affect the widespread adoption of EVs in European countries.

Deliverable D1.1 – initial for COTEVOS project and WP1 - provides information about the state-of-the art in EV - EVSE interaction and interaction between the EVSE and the service providers and system operators. Different solutions and products are reviewed and their functionalities are presented. The needs and requirements for interoperability are identified at user/actor level. Furthermore, an inventory of past and present initiatives for mitigating interoperability issues is developed. This information will be provided within further COTEVOS work packages.

Initiatives currently undertaken

In order to reduce current and to avoid future interoperability issues, there is a trend to form consortiums of research entities, universities, standardization bodies and manufacturers. These consortia are typically initiated by EV manufacturers but are also a response to European projects related to this topic (i.e. COTEVOS). Activities performed by such consortia encourage the reduction of interoperability problems between EVs and EVSEs and beyond (EVSE – EVSE Operator, Clearing House, System Operator etc.).

Interoperability must be ensured at different levels:

- energy transfer between EV and EVSE,
- safety for EV, EVSE and involved users,
- information exchange indispensable for controlling energy flow, payment and accounting/financial settlement between the actors involved.

The present EU policy for supporting the EV development encourages the initiatives which can be divided into three groups: standards for European e-mobility market, research on the EV development and the EV manufacturers associations.

[3] The term Interoperability, as used in this document, is defined as the ability of two or more networks, systems, applications, components or devices from the same vendor or different vendors to provide the required functions and services.

The first activity group has been initiated by the European Commission standardization mandates. The standardization mandate M/468 request to CEN, CENELEC and ETSI, refers to interoperability aspects for EV charging in two categories. Category 1 refers to batteries recharging with on-board charger, which should be interoperable with any grid access point, while Category 2 deals with interoperability between any EV and any off-board charger. The goal of standardization Mandate M/490 ("Standardization Mandate to European Smart Grid deployment") is to elaborate and control the present state of standardization according to common European communication technologies, electrical infrastructure and related processes and services, which should lead to interoperability of e-mobility and support of smart grids development.

Both mandates aroused interest of numerous R&D bodies. Currently, there are several on-going projects such as Mobincity, ICT4EVEU, Power Up, Green eMotion, SmartCEM and Molecoules concerning roaming, user services (mobility information), EVSE access, EVSE management, EV management, V2G services and Plug-in. These projects address the following interoperability related aspects:

- e-roaming (cross billing services, integration of payment methods),
- cross border charging,
- user services (charging point booking),
- EVSE access (monitoring of the network status – energy pricing, car location, charging point usage in-use status),
- EV integration in the overall mobility systems,
- ICT services implementation,
- integration of Smart Connected Electro-mobility,
- development of electro-mobility and communication service,
- integration of charging station management with power provider, charging point booking, payment,
- support pan-European interoperability,
- adoption of electro-mobility in all types of road transport,
- V2G interface development and conformance testing.

The e-mobility is also supported by associations of EV and EVSE manufacturers. There are two leading associations: SAE International (Society of Automotive Engineers International) - including ACEA, CLEPA and EURELECTRIC - and association of Audi, BMW, Daimler, Ford, General Motors, Porsche and VW (established in 2011). Both associations deal with the connector-inlet interoperability issue. Their one of major achievements is the development of Combo2 connector. ACEA also indicates two phases of e-mobility (for passenger and light commercial vehicles) expansion timeframe: phase 1 and phase 2. Phase 1 reflects current situation and should be seen as an initial step for a broader introduction of electrically chargeable vehicles in the EU. Phase 2 (starting in 2017), enabling global harmonized rules, should result in reduction of solutions discrepancies on the market.

According to ACEA, basic communication should be in line with the IEC 61851-1 standard that has to be applied on all charging stations. The detailed specification of ISO/IEC 15118 enables reliable charging using this standard. This standard supports different use cases like smart grid integration, roaming for charging abroad and also guarantees customer privacy, authentication and identification purposes. ISO/IEC 15118 describes communication between the car and the infrastructure (charging point) using IEEE 1901 Profile Green PHY

on CPLT/PE. ISO/IEC 15118 does not include and describe any further details for enabling the infrastructure behind the charging point for smart grid solutions, for roaming services and so on; furthermore, it does not include any details of the internal process of handling the data of this ISO/IEC 15118 protocol inside the car and the Control Units being part of the car.

EV and EVSE

Thanks to the rapid development of technical solutions for the e-mobility and activities of the standardization bodies and stakeholders, the crucial and most elementary problems such us discrepancies in charging connectors, charging procedures etc., seem to have already been solved. On the other hand, growing e-mobility market is continuously introducing new functionalities and novel problems and interoperability issues arise such as Smart Charging and V2G. In these fields, much effort must be put in order to obtain fully an interoperable system. Current projects and activities for Smart Charging and V2G cover only a small part of problems. They are important; however, further R&D is highly needed.

The main functionality of EVs is transportation. However, traveling within EV is limited now mainly to the city use and commuting. To meet EV users' expectations, EV should allow also for long distance journeys. Therefore, a large number of charging stations allowing fast recharging is essential. This can be accomplished by using a wide range of DC fast charging equipment on condition that connectors of any EVSE are compatible with the inlets of any EV.

As it has been suggested above, simple functionality of the e-mobility (which means EV use only for commuting and home charging) is already provided and there is no interoperability problem. Nevertheless, extension of the simple functionality and introduction of the Smart Charging and V2G needs technical and organizational development. Nowadays an on-board single phase AC charger, for slow (home) EV's battery charging, is most commonly used solution. Fast charging is managed with the deployment of external DC chargers but the charging process is controlled by both the DC charger (off-board) and the EV's BMS (on-board). Three phase AC chargers are rarely used as on-board designs due to relatively high costs that significantly increase their price. Regardless of charger's power, all currently used devices allow only for one direction power flow only. The development of bi-directional chargers itself is not a technical problem but the problem is a high price of such an assembly. Hence, business models do not allow for wide introduction of bi-directional chargers and services developed on their basis.

Another important issue for interoperability and e-mobility is battery. Currently, Li-ion batteries are most common. However, other technologies are under continuous development. Batteries such as lithium-air, which can be charged with much higher currents and which have higher energy density, may replace the Li-ion batteries in the future. The process of battery charging is controlled by BMS, which prevents battery from deep discharge, damages (caused by wrong charging parameters) and which ensures long battery lifetime.

The battery issue is the major reason for the so called EV user "range anxiety". Low battery capacity causes that EVs cannot be used for long journeys and their use is much dependant on the charging access points (AC) or charging stations (DC). In order to mitigate the "range anxiety" several EV manufacturers introduced the range extender. It doubles the EV driving range but the range extender is nothing more than additional combustion engine with an alternator charging the battery during a car ride.

Another approach to overcome the “range anxiety” is to improve the knowledge of the EV user about the way of EV use and provide more accurate information to the driver. It is observed that remote and mobile interfaces start playing a key role. They improve the comfort of EV usage (providing important information) and become a vital tool supporting the management of charging process and energy consumption. Currently, most information is provided by Human-Machine Interface (HMI). Additionally, HMI can be also used to perform control over EV, allowing for manual charging session scheduling. Nevertheless, for supporting dynamic e-mobility (market based) and Demand Side Response development, a more advanced HMI will be required.

Driven by the EU policy and initiated directly by the governments of Member States, the process of rapid deployment of public charging infrastructure occurs all over Europe. A similar drive is observed in standardisation of EVSEs, which particularly concerns connectors and inlets. However, among various solutions, charging systems (Combined Charging System) provided by the Combo2 connector have been more and more common and are supported by the EU. The connector allows for charging with both alternating and direct current and at various power levels. Meanwhile, there are other standards, such as Japanese (CHAdeMo) and North-America (SAE J1772, UL 2251). Japanese CHAdeMo is supported by the Japanese EV manufactures such as Nissan, Mitsubishi, which may lead to establishing this standard in Europe together with Combo2.

The LV networks, which are typical for the urban area, are able to accommodate the largest number of EVs without negative results for the power system. Single feed networks, typical in the rural areas, may need some reinforcement to integrate EVs in higher quantities than today. Security of supply, due to the network configuration differences, is much lower in rural areas than in urban ones. This results in some kind of risk that EV user living outside the city/town will not be able to get to work because of discharged EV battery.

Any kind of grid adjustment requires real time data exchange between all systems involved in charging process (EV, EVSE, EVSP, SCADA). A dominant tool for network management among DSOs is SCADA. Therefore, communication for e-mobility needs to be coherent with currently existing system. For the communication behind the substation, the PLC meets all current requirements.

EV chargers are classified as A-class equipment. In spite of a variety of charging modes, which may affect the grid in different ways, it is recommended to introduce a dedicated class for them within IEC 61000-3-2. It is worth mentioning that basic EMC standards do not include any information about the usage of EV’s batteries as energy storage for ancillary services.

Regarding communication tests, there is a number of standards, such as SAE J2894, SAE J2293, UL 2594 and UL 2202 (implemented in North-America), IEC 61851, IEC 15118 and IEC 61851 (implemented in Europe) and CHAdeMo (employed in Japan).

Concerning the communication interface between EV/EVSE and system operator, IEC 61850, SAE J2847, OCPP and OCPP are used according to region of the world . The Interface between EV/EVSE and the grid could be employed with IEC 61859, OCPP and SAE J2847, while the interface between EV/EVSE and backend (e.g. system operator, clearing house) could be done by OCPP. However, the standardized interface between EV/EVSE to backend is still open.

Further scenarios in e-mobility

According to the presented analysis, the following scenario of e-mobility seems to be adequate. The scenario assumes sustainable development of e-mobility as well as the increasing role of EVs in the operation of electrical power networks with high penetration of Distributed Generation and Renewable Energy Sources (RES). The future scenario distinguishes two cases of EV use:

- travelling/commercial use (20%),
- EV used for commuting. (80%).

In the first case, an access to (public and semi-public) charging stations and short charging time are most important for users. Therefore, standardization should ensure the possibility of fast charging of any EV at any station equipped with DC fast charger, e.g. at petrol stations where any car (on LPG, gasoline, bio-fuel, diesel oil) may be refuelled. Additionally, the charging process should be controlled by on-board battery/energy management unit, which meets/covers an optimal charging schedule (considering EV user defined constraints and battery depreciation).

Assuming straight forward plug-and-charge scenarios, the electricity grid will be out of balance even more often, as the EV electricity demand will typically peak around 19:00 (in case of large EVs penetration). In the nearest future (up to 2020) the forecasted share of EV in mobility market will be fluctuated from 5 to 10%. It is too low to affect network operation significantly. However, if the share will exceed 10%, then the demand side response of charged EVs is vital to keep technical standards of network operation. Additionally, taking into account additional services (V2G and Smart Charging), the network should be enhanced and a novel approach to the grid operation would be indispensable. According to the quality of the grid operation it is suggested to keep the short-circuit at least at the level of 0,7 MVA.

Research revealed that cars used by private users for commuting are left in garages, car parks, etc. most of the day, i.e. for approximately 23 hours per day. It seems likely that EVs would be used in a similar way. Thus, during this time the EV's battery could be used by another entitled entity, such as the system or EVSE operator. A large number of EVs may constitute distributed energy storage with significant capacity (e.g.: 1 million of EVs ready to travel for 2 h with power of 50 kW may reflect power of 50 GW and capacity 100 GWh). It is worth mentioning that electrical power systems operators are in charge of utilizing such storage at every moment of a day. However, in order to ensure the efficient usage of the distributed energy storage, each EV should be equipped with bi-directional AC/DC power charger that allows not only for energy accumulation but also for electricity generation. Additionally, the (dis)charging process should be remotely controlled by an operator, thereby taking the (instantaneous and contractual) constraints from the EV user/owner into account. The context as described above sets additional standardization challenges required to be able to meet the interoperability requirements referring to access points, communication protocols, etc. Mobile and distributed energy storage also raises potential interoperability issues concerning payments and settlements, especially in case of charging and discharging at different spots and with different tariffs.

E-mobility services – V2G and Smart Charging

Further development of the e-mobility is subjected to the introduction of novel services such as Vehicle to Grid (V2G) and Smart Charging. Supporting technologies are (at the

moment of reporting) still at the demonstration stage. Both types of solutions require the cooperation of network and system operators with EVSE Operators according to usage of EVs for services. It is very important for V2G and Smart Charging development is business model, which should answer several questions about financial flows, responsibilities, organization etc. Currently, the detailed final business model for V2G and Smart Charging is not defined. There are a few, simultaneously existing but without any implementation.

The CEN/CENELEC (and COTEVOS as well) definition of Smart Charging suggests that it is an optimised process of battery charge assuming one direction of energy flow (from the grid to the battery). Charging process in the Danish Nikola Project includes charging parameters such as timing, rate and direction of the energy exchange between EV and the grid. Thus ability for changes of the energy exchange direction should be defined because it extends the Smart Charging impact on the grid and in the future will be commonly used as it is anticipated that the majority of EVs will only support the Mode 3 PWM signal in the coming years.

The required communication, when not defined, accepted and rolled-out properly, is likely to result in major interoperability issues and should therefore be considered first. The question to be addressed is how DSOs should communicate with an EVSE Operator providing a service and how communication with the EV (and ultimately the EV owner) should take place. The issue refers particularly to the communication between EV and EVSE, EVSE and EVSE Operator, EVSE Operator and DSO, EVSE Operator and Energy Provider. For all these interfaces well-defined, accepted and properly implemented standards shall be present.

Nowadays, end user portals are a part of Smart Charging environment, which is available online and which can be used by EV user to optimize the charging process of batteries. However, there is no standardisation in this field, which could ensure interoperability EV user mobile devices with the online application. Therefore, the access to the portals and their content (available services, information, filters) should be unified within the EU to ensure accessibility and comfort for potential users. The second solution is the collection of information about EVSEs in a single data base around the EU which would be updated online, directly by each EVSE. The access to the data base should be provided by unified mobile application dedicated to EV users according to the user's needs (i.e. searching of charging station with specific parameters, booking, navigation).

It should be highlighted that services such as frequency adjustment, voltage control, reactive power control, phase balancing, islanded microgrid operation and black start require real time regulation and EV charger should be connected to an electrical protection device or regulator. Consequently, a charger should be off-board with precisely defined localization and built according to local network conditions. In case of services such as congestion management, transformer and lines overload management, frequency regulation and peak shaving etc. the charger must be directly controlled by the network operator (DSO or TSO) via a direct communication connection. For these cases, which have been described above Smart Charging structure (services provided by off-board chargers only) rises doubts as to a suboptimal structure which can be a barrier for common use. Additionally, Smart Charging can be significant for DSO/TSO only if most of EVs will participate in the charging spot preferred by the network operator. IT requires installation of proper EVSE at every public charging spot indicated by the DSO/TSO. Accordingly, EVSE should be inexpensive and easy to set. For that reason it seems to be a justified usage of on-board chargers, which can

be able to exchange energy in two directions for Smart Charging. Charging parameters related to an optimal battery charging process could be programmed by the EV manufacturer, while charging schedules and services availability could be updated by the user, regardless of the localization of the grid connection. Additionally, after connecting it to the grid, EV charger could be controlled by the DSO/TSO within a specific area. In this approach each EV user is a mobile prosumer controlled by the network operator and settled with the energy consumed and injected to the grid according to the current tariff but regardless of the localization and the duration of the grid connection.

Despite the technical aspect, there is also an important social aspect. The surveys referred to in this report show that current and potential EV owners worry about the impact of V2G on the condition of batteries. They also highly appreciate an access to a fully charged EV. This means that a workable business case around V2G services is important but far from trivial!

Interoperability assessment methodology

Various initiatives, which have been taken by the European Commission and EV manufacturers, have already led to cover most of the standardization gaps. The uncovered yet or not published can be found in the SGAM. Most of these gaps involve communication with DSO or any new stakeholders such as flexibility aggregators. Additionally, the smart grid trend in power electricity causes evolution of existing standards related to EV, supporting integration of EVs with smart grids.

Most promising service is a response to the demand but there are many ways in which it can be carried out and it depends on energy regulation and DSO strategies. There are many factors affecting these decisions related e.g. costs of communication infrastructures, moreover, nowadays it is difficult to directly indicate how the service will evolve and what the final form of it would be. The most possible solution might be that of including EVSE control in an asset control strategy that a DSO might already have, for example, through energy management systems or smart meters at homes.

The methodology of use cases definition is crucial to ensure interoperability in e-mobility. Nowadays it is a standardised procedure to define and present them but the methodology is not completed yet and requires further development.

The testing methodology is also already presented by the SG-CG and the process based on profile specification, use case identification and the V-model method.

With respect to the identified testing capabilities of COTEVOS and DERlab consortium infrastructures, some testing requirements, procedures and infrastructures are still needed. Therefore, the external partners (i.e. outside COTEVOS) and the DERlab consortium will be also taken into account in order to identify any gaps in EV-related testing infrastructures.

COTEVOS consortium has identified research infrastructures outside its consortium in Europe and the US and DERlab is an operating agent of Smart Grid International Research Facility Network (SIFRN), part of IEA Smart Grids Action Network (ISGAN), COTEVOS will approach all international testing infrastructures with a proposal for laboratory cooperation.

Interoperability assessment

Energy distribution and transmission as a part of the electricity sector is highly dependent on from regulations. Thus regulation aspects are crucial for new business models

and will affect functionalities and services that can be developed. Consideration of all possibilities is difficult due to a high number of use cases and interaction between actors and systems. Although existing standards can already provide many added value services, the Smart Charging process involves EV user and the network, which expands several actors and data sources. The OCCP v2.0, with respect to previous versions, achieved to support new use cases that were defined by the ISO 15118 standard and, as consequence, it extends the communication domain from the EVSE towards the EVSEO. Unfortunately, there are also existing protocols which when combined with the solution proposed may result in inconsistencies causing interoperability issues in the future. The problem seems to involve complex procedures which require more complex testing procedures definition and implementation. Nevertheless, it is necessary to observe the market approach in a certain environment in order to be able to provide most adequate services at lower cost. Therefore, an attention should be drawn to standard development and market adoption of standards to ensure adequacy of services to foster interoperability and market development of e-mobility.

Major identified interoperability issues in the component layer to be considered in COTEVOS

- External mobile device (EV user) - HMI platform (EV)

The external communication is essential for the EV user to get remote access to information about EV, i.e. about the battery SOC of the EV batteries or to receive a massage when batteries are fully charged. The interoperability is related with establishment of the connection between EV user mobile device and EV HMI platform, and their cooperation.

- Customer portal (EVSP) - External mobile device (EV user)

Because of discrepancies in the available software of mobile devices it may happen that EV user will not be able to Log in into the EVSP customer portal.

- HMI Platform (EVSE) - ID Card (EV user)

EV users commonly use loyalty cards for identification. However, the number of EVSPs providing loyalty programs is wide and ID cards may not be compatible with any HMI platform at EVSE.

- Billing system (EVSEO) - Energy Trading Application (EVSP)

If the ID card is compatible with HMI platform but EVSE operator does not have suitable equipment for communication with EVSP.

- Energy Management Gateway (EVSEO) - Energy Management Gateway (DSO)

This is one of most important interoperability issues which should be considered within COTEVOS. Real time communication between EVSEO and DSO is crucial for V2G and Smart Charging services. Such services will not be able to be provided until all interoperability issues are eliminated. For this purpose, existing DSO's SCADA systems

should be consistent with e-mobility systems that are currently under development. The IEC 61850 protocol could be suitable for the needs.

Recommendations to be addressed in the further COTEVOS Work Packages

- the COTEVOS project should come up with concrete solutions for above listed interoperability issues within Europe,
- effort shall be put on ensuring that the proposed solutions will be well received by standardization committees, OEMs, DSOs, e-mobility operators/providers and other stakeholders,
- the COTEVOS consortium shall be aligned with other currently performed initiatives in the field of e-mobility in order to maintain open and broad view on today's interoperability issues.

12 APPENDIX I

Table 59. Overview of regulations related to electro-mobility

Standard/ specification	Title
EC 60479-1 (VDE0140-479-1)	Effects of current on human beings and livestock – Part 1: General aspects
EN 50160	Voltage characteristics of electricity supplied by public networks
EN 55012 (CISPR12)	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of off-board receivers
EN 55025 (CISPR25)	Vehicles, boats and internal combustion engines – Radio disturbance characteristics – Limits and methods of measurement for the protection of on-board receivers
HD 60364-7-722 (being developed at CENELEC)	Low voltage electrical installations – Part 7-722 Requirements for special installations or locations – Supply of electric vehicles
IEC 60364-4-41 DINVDE0100-410	Low - voltage electrical installations - Part 4-41: Protection for safety - Protection against electric shock
IEC 60364-5-53 DINVDE0100-530	Electrical installations of buildings - Part 5-53: Selection and erection of electrical equipment - Isolation, switching and control
IEC 60364-5-54 DINVDE0100-540	Low voltage electrical installations - Part 5-54: Selection and erection of electrical equipment - Earthing arrangements and protective conductors
IEC 60529	Degrees of protection provided by enclosures (IP Code)
IEC 61000-6-2	Electromagnetic compatibility(EMC)– Part 6-2: Generic standards – Immunity for industrial environments
IEC 61000-6-3	Electromagnetic compatibility (EMC) – Part 6-3: Generic standards - Emission standard for residential, commercial and light-industrial environments
IEC 61140 (VDE0140-1)	Protection against electric shock - Common aspects for installations and equipment
IEC 61439-7	Low - voltage switchgear and control gear assemblies - Part 7: Assemblies for specific applications such as marinas, camping sites, market squares electric vehicles charging stations
IEC 61508	Functional safety of electrical/electronic/ programmable electronic safety-related systems
IEC 61850-7-420	Communication networks and systems for power utility automation- Part 7-420: Basic communication structure- Distributed energy resources logical nodes
IEC 61851-1	Electric vehicle conductive charging system - General requirements
IEC 61851-21	Electric vehicle conductive charging system - Part 21: Electric vehicle requirements for conductive connection to an AC/DC supply

Standard/ specification	Title
IEC 61851-22	Electric vehicle conductive charging system - AC electric vehicle charging station
IEC 61851-23	Electric vehicle conductive charging system - DC electric vehicle charging station
IEC 61851-24	Electric vehicle conductive charging system - Control communication protocol between off-board DC charger and electric vehicle
IEC 61980-1	Electric vehicle wireless power transfer systems (WPT) - Part 1: General requirements
IEC 62196-1	Plugs, socket-outlets, vehicle connectors and vehicle inlets – Conductive charging of electric vehicle – Part 1: General requirements
IEC 62196-2	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicle - Part 2: Dimensional compatibility and interchangeability requirements for AC pin and contact-tube accessories
IEC 62196-3	Plugs, socket-outlets, vehicle connectors and vehicle inlets - Conductive charging of electric vehicle - Part 3: Dimensional compatibility and interchangeability requirements for DC and AC/DC pin and contact – tube vehicle couplers
IEC 62351	Data and communication security (Security for Smart Grid) – Power systems management and associated information exchange – Data and communication security
IEC 62443	Industrial communication networks- Network and system security
IEC 62576	Electric double - layer capacitors for use in hybrid electric vehicles -Test methods for electrical characteristics
IEC 62660	Secondary lithium-ion cells for the propulsion of electric road vehicles
IEC 62752	In-Cable Control and Protection Device for mode 2 charging of electric road vehicles (ICRCD)
ISO 11451 Part 1-4	Road vehicles – Vehicle test methods for electrical disturbances from narrowband radiated electromagnetic energy
ISO 11452-1	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 1: General principles and terminology
ISO 11452-10	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 10: Immunity to conducted disturbances in the extended audio frequency range
ISO 11452-2	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 2: Absorber-lined shielded enclosure
ISO 11452-3	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 3: Transverse electromagnetic mode (TEM)cell
ISO 11452-4	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 4: Harness excitation methods
ISO 11452-5	Road vehicles – Component test methods for electrical disturbances from

Standard/ specification	Title
	narrowband radiated electromagnetic energy – Part 5: Strip line
ISO 11452-7	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 7: Direct radio frequency (RF) power injection
ISO 11452-8	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 8: Immunity to magnetic fields
ISO 11452-9	Road vehicles – Component test methods for electrical disturbances from narrowband radiated electromagnetic energy – Part 9: Portable transmitters
ISO 12405-1	Electrically propelled road vehicles –Test specification for lithium-ion traction battery packs and systems - Part 1:High power applications
ISO 12405-2	Electrically propelled road vehicles -- Test specification for lithium-ion traction battery systems - Part 2: High energy applications
ISO 12405-3	Electrically propelled road vehicles – Test specification for lithium-ion traction battery packs and systems – Part 3: Safety performance requirements
ISO 14572	Road vehicles - Round, sheathed, 60 V and 600 V screened and unscreened single- or multi-core cables - Test methods and requirements for basic and high-performance cables (Ed. 2.0)
ISO 16750 Parts 1–5	Road vehicles - Environmental conditions and testing for electrical and electronic equipment
ISO 17409	Electrically propelled road vehicles - Connection to an external electric power supply - Safety requirements
ISO 23273	Fuel cell road vehicles - Safety specifications – Protection against hydrogen hazards for vehicle fuelled with compressed hydrogen
ISO 23274-1	Hybrid-electric road vehicles – Exhaust emissions and fuel consumption measurements – Part 1: Non externally chargeable vehicles
ISO 23274-2	Hybrid-electric road vehicles – Exhaust emissions and fuel consumption measurements – Part 2: Externally chargeable vehicles
ISO 26262 series	Road vehicles - Functional safety
ISO 6469-1	Electrically propelled road vehicles–Safety specifications – Part 1: On-board rechargeable energy storage system (RESS)
ISO 6469-2	Electrically propelled road vehicles–Safety specifications – Part 2: Vehicle operational safety means and protection against failures
ISO 6469-3	Electrically propelled road vehicles – Safety specifications – Part 3: Protection of persons against electric shock
ISO 6469-4	Electrically propelled road vehicles – Safety specifications – Part 4: Post crash electrical safety requirements
ISO 6722-1	Road vehicles – 60V and 600V single-core cables – Part 1: Dimensions, test methods and requirements for copper conductor cables(Ed. 2.0)
ISO 6722-2	Road vehicles – 60V and 600V single-core cables – Part 2: Dimensions test methods and requirements for aluminum conductor cables
ISO 7637-1	Road vehicles – Electrical disturbances from conduction and coupling – Part 1: Definitions and general considerations

Standard/ specification	Title
ISO 7637-2	Road vehicles – Electrical disturbances by conduction and coupling – Part 2: Electrical transient conduction along supply lines only
ISO 7637-3	Road vehicles – Electrical disturbances by conduction and coupling – Part 3: Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines
ISO TR8713	Electrically propelled road vehicles – Vocabulary
ISO/IEC 15118-1	Road vehicles – Vehicle to Grid Communication interface – Part 1: General information and use case definition
ISO/IEC 15118-2	Vehicle to Grid Communication interface – Part 2: Network and application protocol requirements
ISO/IEC 15118-3	Road vehicles – Vehicle to Grid Communication interface – Part 3: Physical and data link layer requirements
ISO/IEC 15118-4	Road vehicles – Vehicle to Grid Communication interface – Part 4: Network and application protocol conformance
ISO/IEC 15408	Information technology - Security techniques - Evaluation criteria for IT security
ISO/IEC 27000	Information technology - Security techniques - Information security management systems - Overview and vocabulary
ISO/IEC 27001	Information technology - Security techniques - Information security management systems - Requirements
ISO/NPPAS 16898	Electrically propelled road vehicles – Dimensional and designation of secondary lithium-ion cells
SAEJ 1773	Electric Vehicle Inductively Coupled Charging
SAEJ 1797	Recommended Practice for Packaging of Electric Vehicle Battery Modules
SAEJ 1798	Recommended Practice for Performance Rating of Electric Vehicle Battery Modules
SAEJ 2288	Life Cycle Testing of Electric Vehicle Battery Modules
SAEJ 2289	Electric - Drive Battery Pack System: Functional Guidelines
SAEJ 2464	Electric and Hybrid Electric Vehicle Rechargeable Energy Storage System (RESS) Safety and Abuse Testing
SAEJ 2929	Electric and Hybrid Vehicle Propulsion Battery System Safety Standard
VDE 0105-100	Operation of electrical installations - Part 100: General requirements

13 APPENDIX II

13.1 Requirements for emission of harmonics generated on AC power lines from vehicle

The measurements of even and odd current harmonics shall be performed up to the fortieth harmonic.

The limits for harmonics emission for EV coupled to the power grid with input current ≤ 16 A per phase are given in Table 60 [44].

Table 60. Maximum allowed harmonics (input current ≤ 16 A per phase) [44]

Harmonic number ***h***	**Maximum authorized harmonic current** **A**
Odd harmonics	
3	2.3
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
$15 \le h \le 39$	0.15 x 15/*h*
Even harmonics	
2	1.08
4	0.43
6	0.30
$8 \le h \le 40$	0.23 x 8/*h*

The limits for input current > 16 A and ≤ 75 A per phase are given in Table 61 [45].

Table 61. Maximum allowed harmonics (input current > 16 A and ≤ 75 A per phase) for equipment other than balanced three-phase equipment [45]

Minimum R_{sce}	**Acceptable individual harmonic current** I_h/I_{ref} **%**						**Maximum current harmonic ratio** **%**	
	I_3	I_5	I_7	I_9	I_{11}	I_{13}	THC/ I_{ref}	PWHC/ I_{ref}
33	21.6	10.7	7.2	3.8	3.1	2	23	23
66	24	13	8	5	4	3	26	26
120	27	15	10	6	5	4	30	30
250	35	20	13	9	8	6	40	40
≥ 350	41	24	15	12	10	8	47	47
Relative values of even harmonics lower or equal to 12 shall be lower than 16/n %. Even harmonics greater than 12 are taken into account in the THD and PWHD in the same way than odd harmonics. Linear interpolation between successive values of R_{sce} is authorized.								

I_{ref} = reference current; I_h = harmonic current component.

In Table 61 R_{sce} is a short-circuit ratio - characteristic value of a piece of equipment defined as follows:

a) $R_{sce} = S_{sc}/(3S_{equ})$ - for single-phase equipment and the single-phase part of hybrid equipment;

b) $R_{sce} = S_{sc}/(2S_{equ})$ - for interphase equipment;

c) $R_{sce} = S_{sc}/S_{equ}$ - for all three-phase equipment and the three-phase part of hybrid equipment

where

S_{sc} is short-cicuit power of the network

S_{equ} is rated apparent power of the equipment calculated from the rated current I_{equ} of the piece of equipment stated by the manufacturer and the rated voltage U_p (single phase) or U_i (interphase) as follows:

a) $S_{equ} = U_p\, I_{equ}$ - for single-phase equipment and the single-phase part of hybrid equipment;

b) $S_{equ} = U_i\, I_{equ}$ - for interphase equipment;

c) $S_{equ} = 3\, U_i\, I_{equ}$ - for balanced three-phase equipment and the three-phase part of hybrid equipment;

d) $S_{equ} = 3\, U_i\, I_{equ,max}$ - for unbalanced three-phase equipment, where $I_{equ,max}$ is the maximum of the RMS currents flowing in any one of the three phases.

The coefficient *THC* (total harmonic current) is the total RMS value of the harmonic current components of orders 2 to 40

$$THC = \sqrt{\sum_{h=2}^{40} I_h^2}$$

and coefficient *PWHC (*partial weighted harmonic current) is total RMS value of a selected group of higher order harmonic current components (in IEC 61000-3-12 Standard from order 14 to order 40), weighted with the harmonic order *h*

$$PWCH = \sqrt{\sum_{h=14}^{40} hI_h^2}\ .$$

The limits for three-phase charging equipment with input current > 16 A and ≤ 75 A per phase are given in Table 62 [45].

Table 62. Maximum allowed harmonics (input current > 16 A and ≤ 75 A per phase) for balanced three-phase equipment [45]

Minimum R_{sce}	**Acceptable individual harmonic current I_h/I_{ref} %**				**Maximum current harmonic ratio %**	
	I_5	**I_7**	**I_{11}**	**I_{13}**	**THC/ I_{ref}**	**PWHC/ I_{ref}**
33	10.7	7.2	3.1	2	13	22
66	14	9	5	3	16	25
120	19	12	7	4	22	28
250	31	20	12	7	37	38
≥ 350	40	25	15	10	48	46
Relative values of even harmonics lower or equal to 12 shall be lower than 16/n %. Even harmonics greater than 12 are taken into account in the THD and PWHD the same way than odd harmonics. Linear interpolation between successive values of R_{sce} is authorized.						
I_{ref} = reference current; I_h = harmonic current component.						

If at least one of the following conditions is fulfilled:

a) The 5th and 7th harmonic currents are each less than 5 % of the reference current during the whole test observation period.
NOTE: This condition is normally fulfilled by 12 pulse pieces of equipment.

b) The design of the piece of equipment is such that the phase angle of the 5th harmonic current has no preferential value over time and can take any value in the whole interval [0°, 360°].
NOTE: This condition is normally fulfilled by converters with fully controlled thyristor bridges.

c) The phase angle of the 5th harmonic current related to the fundamental phase-to-neutral voltage is in the range of 90° to 150° during the whole test observation period.

limits for three-phase equipment with input current > 16 A and ≤ 75 A per phase are given in Table 63 [45].

Table 63. Maximum allowed harmonics (input current > 16 A and ≤ 75 A per phase) for balanced three-phase equipment under specific conditions [45]

Minimum R_{sce}	**Acceptable individual harmonic current I_h/I_{ref} %**				**Maximum current harmonic ratio %**	
	I_5	**I_7**	**I_{11}**	**I_{13}**	**THC/ I_{ref}**	**PWHC/ I_{ref}**
33	10.7	7.2	3.1	2	13	22
≥120	40	25	15	10	48	46
Relative values of even harmonics lower or equal to 12 shall be lower than 16/n %. Even harmonics greater than 12 are taken into account in the THD and PWHD the same way than odd harmonics. Linear interpolation between successive values of R_{sce} is authorized.						
I_{ref} = reference current; I_h = harmonic current component.						

For the application of EN 61000-3-12 to assessment of "RESS charging mode coupled to the power grid" only the limits given in Tables 2 and 3 for R_{sce} = 33 should be used, because EV may be connected at any available supply.

The observation time to be used for the measurements shall be as for quasi-stationary equipment, as defined in IEC 61000-3-2.

13.2 Requirements for emission of voltage changes, voltage fluctuations and flicker generated on AC power lines from vehicle

The limits for voltage changes, voltage fluctuations and flicker emission on AC power lines generated by EV coupled to the power grid are given in IEC 61000-3-3 [46].

For the equipment with input current ≤ 16 A per phase flicker indicators are put together in Table 64.

Table 64. Maximum allowed flicker indicators (input current ≤ 16 A per phase) for single phase or three-phase equipment

No.	Flicker indicator	Maximum flicker indicator value
1	Short-term flicker severity P_{st}	1.0
2	Long-term flicker severity P_{lt}	0.65

The limits concerning voltage changes are given bellow:

- T_{max}, the accumulated time value of *d(t)* with a deviation exceeding 3,3 % during a single voltage change at the EUT terminals, shall not exceed 500 ms;
- the maximum relative steady-state voltage change, d_c, shall not exceed 3,3 %
- the maximum relative voltage change d_{max}, shall not exceed 4 % without additional conditions.

Terms and definitions used:

d(t) - (voltage change characteristic) time function of the relative RMS voltage change evaluated as a single value for each successive half period between zero-crossings of the source voltage, except during time intervals in which the voltage is in a steady-state condition for at least 1 s:

d_c - maximum steady state voltage change during an observation period

d_{max} - maximum absolute voltage change during an observation period

T_{max} - maximum time duration during the observation period that the voltage deviation *d(t)* exceeds the limit for *d*c

For some specific equipment, if the way of using is intended no more than twice per day, the limits may have higher values (up to 7%). There are no conditions specified for electric cars in the standard.

The limits for single phase or three-phase equipment with input current > 16 A and ≤ 75 A per phase, according to requirements defined in EC 61000-3-11, are the same as those in EC 61000-3-3 [46].

14 APPENDIX III

The basic explanation of the diagram (described in the Chapter 8.5.6), as reported in the OCPP standard document is following:

- In the diagram section marked with 'A': after authorization the EVSE will set a maximum current to use via the PWM signal. This limit is based on a (default) charging profile that the EVSE had previously received from the Local Controller. The EV starts charging and a TransactionStarted is sent to the Central System.
- In the diagram section marked with 'B': while charging is in progress the EVSE will continuously adapt the maximum current according to the charging profile. Optionally, at any point in time the Local Controller may send a new charging profile to the EVSE that shall be used as a limit schedule for the EV.

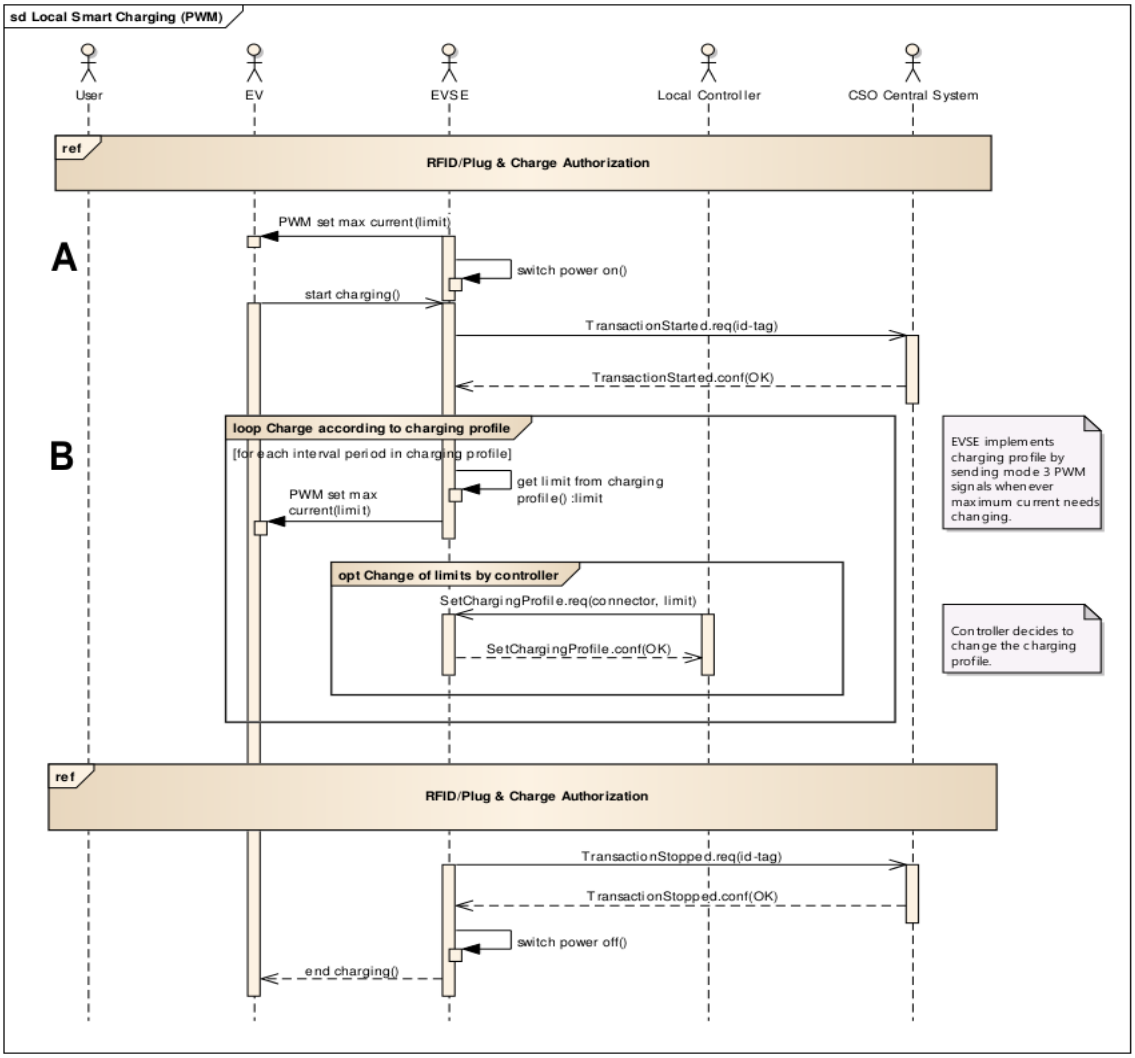


Figure 126. OCPP mode 3 (PWM) charging - Local controller [118]

In case of ISO/IEC 15118 communication between the Charging Points and the vehicles, the overall sequence diagram is shown in the following figure.

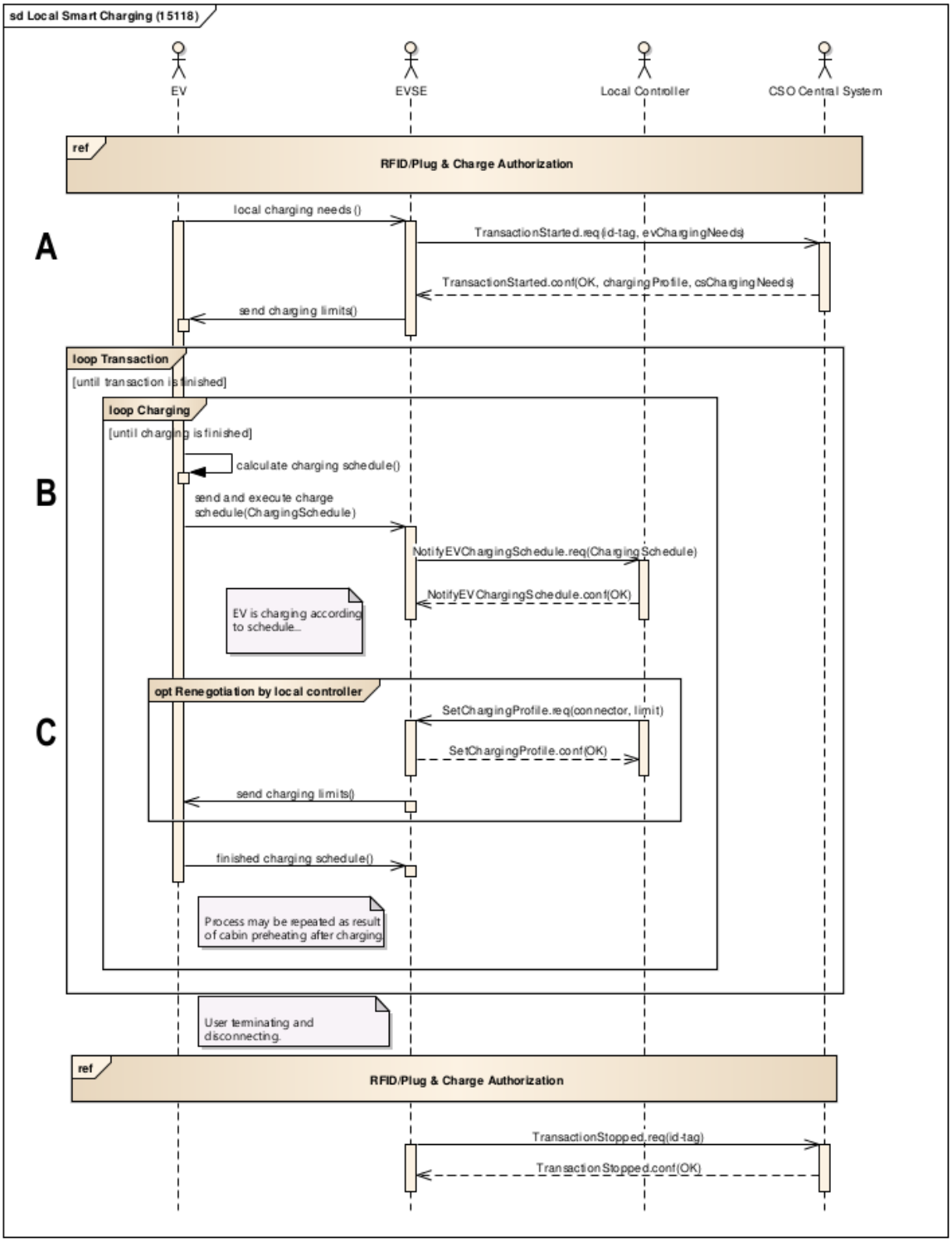


Figure 127. OCPP Smart Charging according to ISO/IEC15118 - Local controller [118]

The basic explanation of the diagram, as reported in the OCPP standard document, is the following:

- In the diagram section marked with 'A': the EV sends its local charging needs immediately after authorization. This is reported to the Central System with

TransactionStarted. Central System responds with a charging profile that the EV shall use as a limit schedule. The limit schedule can also be based upon charging needs that the EV owner has provided to the Central System. This way, for example, the EV owner can instruct the EVSE to provide no more than 4 kWh, even though the EV might be able to charge a lot more.

- In the diagram section marked with ‘B’: the EV calculates a detailed charging schedule and sends it to the EVSE. The EVSE will communicate the actual charging schedule back to the Local Controller.
- In the diagram section marked with ‘C’: optionally, at any point in time the Local Controller may send a new charging profile to the EVSE that shall be used as a limit schedule for the EV. In that case these limits are sent to the EV and the process returns to the top of the loop 'Charging', causing it to recalculate a charging schedule. The loop 'Charging' terminates when the entire charging schedule has been executed. If cabin preconditioning is required after charging has finished, then the process will jump back to the top of the loop 'Transaction' to calculate a schedule needed for cabin preconditioning.

In case of absence of a local controller, all its functions are performed by the Central System. Apart from this, the sequence diagrams are exactly the same as the ones already illustrated, and are reported in the following two figures.

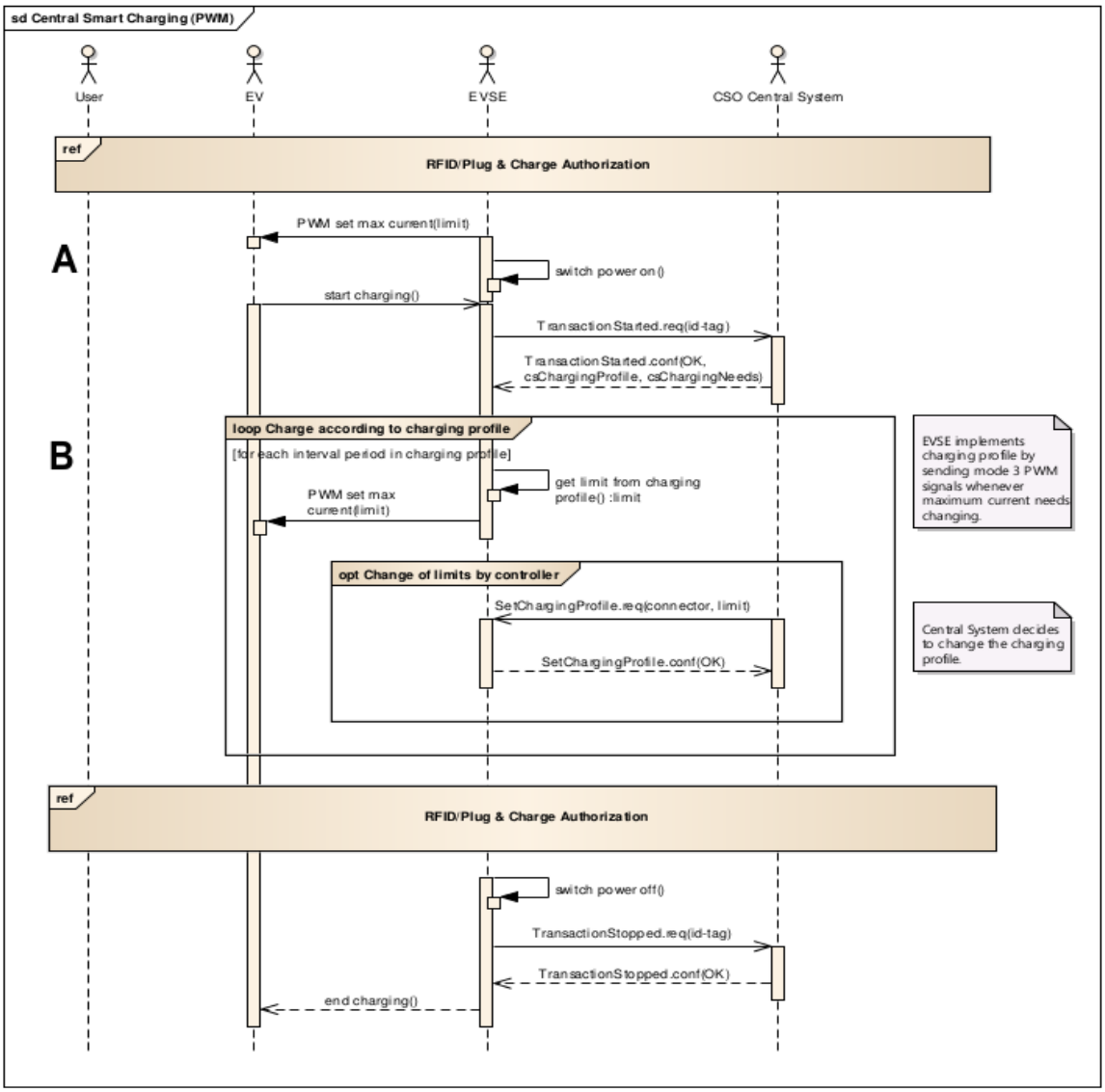


Figure 128. OCPP mode 3 (PWM) charging - Central controller [118]

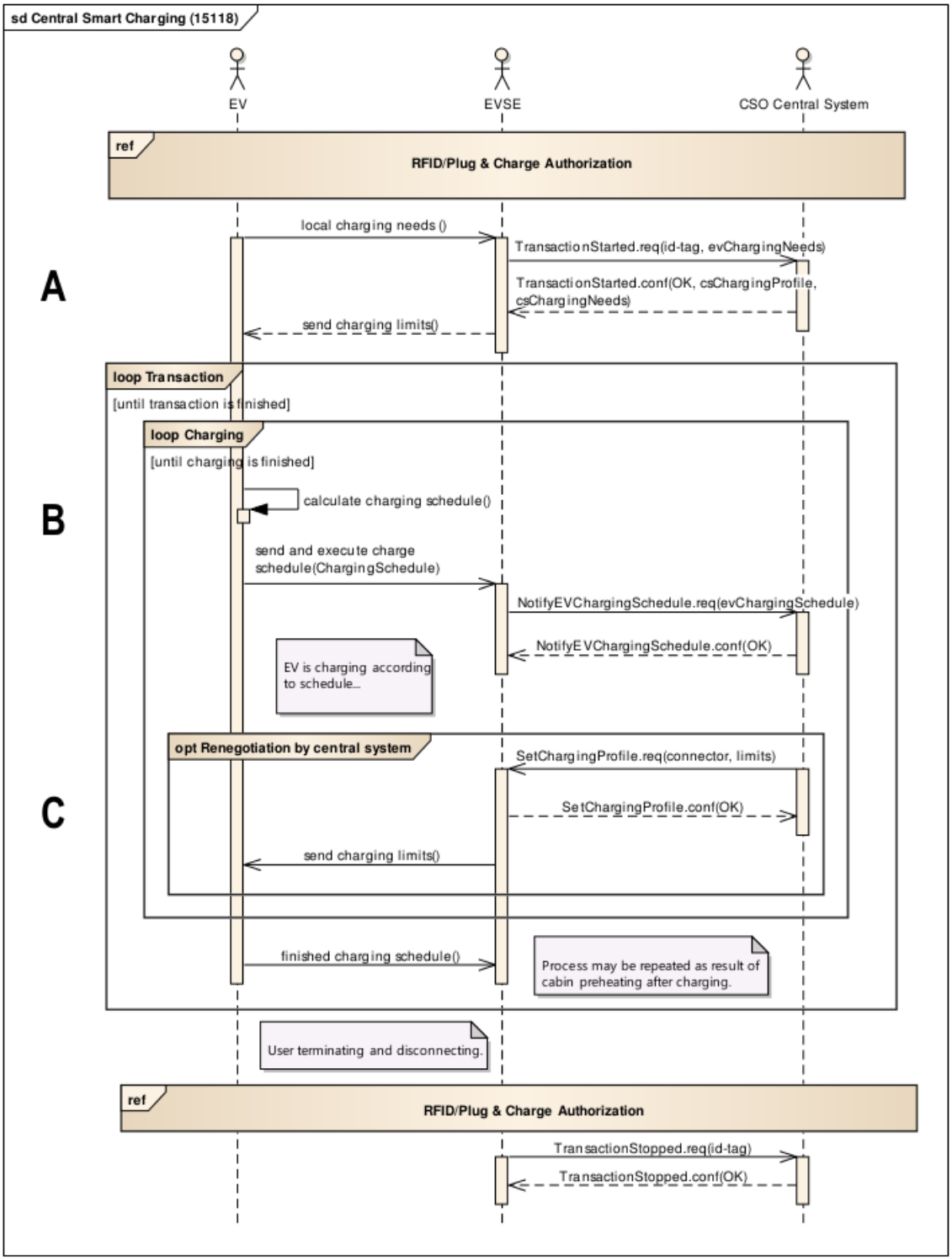


Figure 129. OCPP Smart Charging according to ISO/IEC15118 - Central controller [118]

15 APPENDIX IV - Form used for collecting information on the current EV-related infrastructure capabilities

Overview of EV infrastructure capabilities

DERlab database of DER and Smart Grids Research Infrastructure is an international information access point to the leading research facilities in the field of Smart Grids. DERlab association invites the Electric Vehicle research and testing facilities of its partner institutes be presented in the database. Please fill up the form with the technical specifications of your laboratory.

Company:	Logo (to be attached if not already transmitted)
Country:	Please attach a Picture/Image of the research institute

Laboratory:
General Description (100 words): (If you would like to provide more detailed technical specifications of your laboratory and testing infrastructure, you may attach technical specification fact sheets, flyers etc. to be also published.)
Static equipment:
Mobile equipment:
EV testing capabilities: (Describe, what can currently be tested at your laboratory (e. g. EV/EVSE/Cable/plugs, interoperability testing, different technologies)
Standards compliance: Which standards can currently be tested (full or partly) (e.g. IEC 61851, IEC15118, OCPP 2.0, IEC 62196, inductive charging)
Testing services offer: (Describe if any)
Quality management: (Describe, which quality standards, protocols and certifications (e.g. ISO/IEC 17025, ISO 9001, DERri [EC FP7 2009-2013] Protocol) are complied in your laboratories)
Optional: Participation in EV-EVSE interoperability oriented projects (Describe if any; previous, ongoing)
Optional: E-mobility industry partnership (List if any; OEMs, car manufacturers, etc.)
Optional: future plans to expand and/or build new laboratories in this research field
[ ] I am interested in participating in round robin testing activities in the framework of project COTEVOS (see information below) [ ] I am interested in participating in the definition of Electric Vehicles test procedures.
Technical contact person: (Name and contact details)

This form is filled in by (Name + Company stamp)

_____ Date _____

[ ]I agree this technical laboratory information can be transmitted to the DERlab database of DER and Smart Grids Research Infrastructure and be listed as a company providing research and testing services in the field of Electric Vehicles.

COTEVOS - Developing Capacities for Electric Vehicle Interoperability Assessment

In the project COTEVOS (Concepts, Capacities and Methods for Testing EV systems and their interoperability within smart grids), the interoperability of Electric Vehicles and their smart charging will be assessed in several laboratories according to the new test procedures developed in COTEVOS. **We welcome also external laboratories to participate to this work.**

- To set-up procedures for interoperability testing
- To perform the tests, according to inter-laboratory comparison or to round-robin tests
- To define and, when possible, set-up laboratory capabilities to offer new tests, based in the previous results and, obviously, the expected needs and business opportunities.

Further information can be found on www.cotevos.eu

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