DERlab

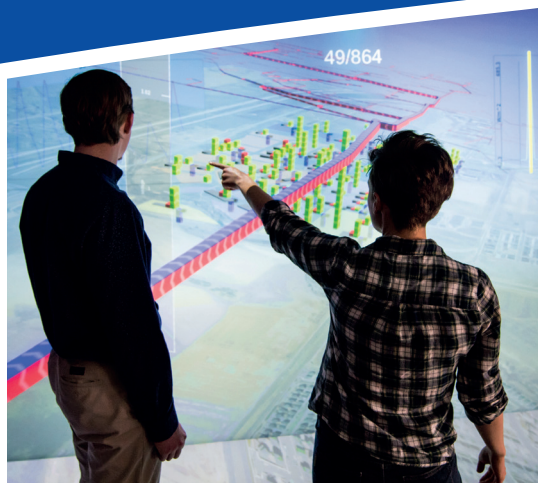
**DERlab**

European Distributed

Energy Resources Laboratories

# Activity Report 2018-2020

## The Pan-European Smart Grid: Innovative Tools and Demonstration Activities for Future Grid Planning and Operation

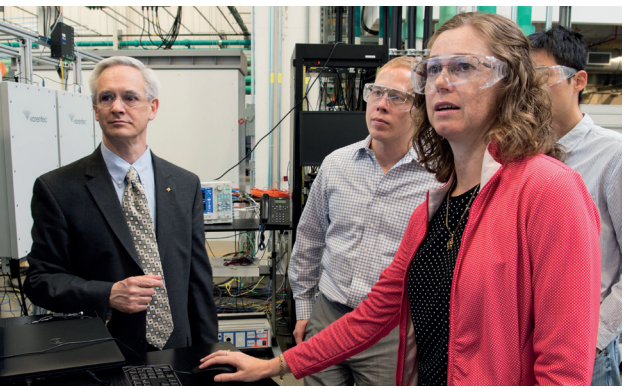



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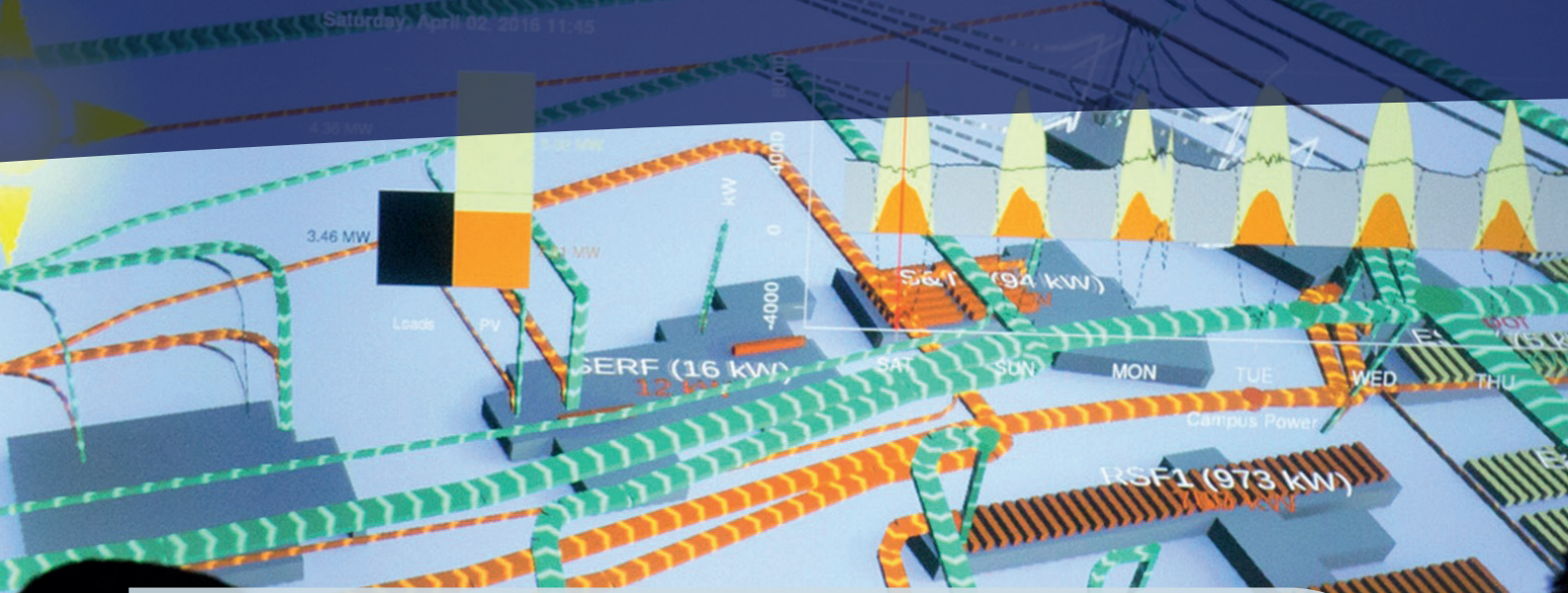
Photo: Dennis Schroeder, NREL




# Contents

Photo: Dennis Schroeder, NREL

# Nomenclature

**CHIL** Controller Hardware in the Loop

**CHP** Combined Heat and Power

**CVC** Coordinated Voltage Control

**DER** Distributed Energy Resources

**DG** Distributed Generation

**DMS** Digital Measurement System

**DSM** Demand Side Management

**DSO** Distribution System Operator

**EHV** Extra High Voltage

**EMSP** E-Mobility Service Provider

**ESCO** Energy Service Companies

**EVSE** EV Supply Equipment

**EVSEO** Electric Vehicle Supply Equipment Operator

**FMI** Functional Mock-up Interface

**FRT** Fault Ride Through

**G3M** Grid Management and Maintenance Master Framework

**GHG** Greenhouse Gas

**HIL** Hardware in the Loop

**HVDC** High Voltage Direct Current

**I-V** or **(V-I)** Current-Voltage

**LV** Low Voltage

**LVRT** Low Voltage Ride-Through

**MPPT** Maximal Power Point Tracking

**MV** Medium Voltage

**OEM** Original Equipment Manufacturer

**OGEMA** Open Gateway Energy Management Framework

**PCC** Point of Common Coupling

**PHIL** Power Hardware in the Loop

**PID Controller** Proportional Integral Derivative Controller

**PID** Potential Induced Degradation

**PLC** Programmable Logical Controller

**PMU** Phaser Measurement Unit

**PV** Photovoltaics

**RES** Renewable Energy Sources

**RI** Research Infrastructure

**RTDS** Real Time Digital Simulator

**RUE** Rational Use of Energy

**SDK** Software Development Kit

**SGAM** Smart Grid Architecture Model

**SMX** Smart Meter Extention

**SRA** Strategic Research Agenda

**TRL** Technology Readiness Level

**TSO** Transmission System Operator

**V2X** Vehicle-to-Everything

**WECC** Western Electricity Coordination Council

# DERlab Association

DERlab is the network of leading research institutes working together for the grid integration of distributed power generation. The association develops joint requirements and quality criteria for the connection and operation of Distributed Energy Resources (DER) and strongly supports the consistent development of DER technologies. DERlab offers testing and consulting services on grid integration of distributed generation and conducts research on a wide range of related topics, such as:

- Interconnection requirements of DER
- DER and smart grids related R&D
- Grid-connected storage
- Electromagnetic compatibility requirements for DER
- Static converters in grids
- DER testing procedures
- Ancillary services
- Communication
- Photovoltaic modules
- Hardware-in-the-loop investigations and testing
- Network protection
- Electric vehicles

**DERlab e. V. Board**

From left to right:
Prof. Graeme Burt, Spokesperson (University of Strathclyde, UK), Maria-Luciana Rizzi (RSE, Italy), Roland Bründlinger (AIT, Austria), Dr. Philipp Strauss (Fraunhofer IEE, Germany), Prof. Peter Vaessen (DNV GL, Netherlands)

## DERlab Members

# Foreword

The pace of change present in our energy systems continues unabated around the world, with a strong and ongoing commitment to decarbonisation by respective policy makers. If anything, their commitment has been solidified by the wider societal awareness of climate issues and indeed a shared expectation of industry and governments to embark on emergency response measures. **At the same time, a growing recognition has emerged of the need for whole systems approaches that incorporate integrated energy systems solutions that architect power, heat and transport solutions. This presents new demands on grid planners, new challenges on system operators, as well as new opportunities for developers of innovative technology and operators of test infrastructures.**

As well as this broader interest in multiple energy vectors, grid operators are seeing new dynamic behaviours and increased complexity, with the growing penetration of power electronics based technologies and arrival of new market entrants offering new flexibility services. Advances in digitalisation are contributing to greater observability and increased decentralisation, to effect improved monitoring and control. At the same time, the recognition of best in class solutions for adoption in "business as usual", and design of schemes that are future-proof to emergent behaviour, if anything is becoming more challenging for the sector. And as organisations begin to see phrases such as "net zero operation" increasingly appear in strategy documents, the requirement to support planning and investment cases with evidence that de-risks decision making will only increase.

These trajectories of change in the energy sector all present new demands for support from the world-class laboratories of the DERlab Association. **The validation and testing procedures offered by the state-of-the-art facilities of the DERlab membership are increasingly essential in providing pathways to accelerated de-risking and systems-proving.** The maturity that has been achieved in recent years in rigorous testing regimes, incorporating hardware-in-the-loop methodologies, and associated troubleshooting approaches, is already delivering value to a wide range of stakeholders, enhancing the effectiveness of field trials, and supporting deployment and scale-up. Moreover, the emergence of distributed laboratories is further enhancing the scale and impact of testing infrastructures.

**DERlab and its members continue to formalise the testing standards that will enable the solutions required of integrated energy system operation, while finding new ways to validate complex systems performance. The ongoing investments in the DERlab testing environments and efforts of our dedicated teams are enabling the provision of new grid flexibility resources, accelerating sector innovation, enhancing grid resilience, and mitigating new and unforeseen error modes. The work of the association remains essential to the realisation of the future, decarbonised and flexible power grid.**

**Prof. Graeme Burt**
DERlab Spokesperson as of 2019
University of Strathclyde

# Introduction

**Diana Strauss-Mincu**

*DERlab General Manager*

The European Union has set out ambitious goals for the design and operation of the European interconnected energy system, to be achieved by 2050. **These goals involve the integration of a higher concentration of renewable energy sources into the electrical power system, as well as the implementation of significant energy efficiency measures.**

As more distributed generation is integrated into medium voltage grids, the interaction between transmission and distribution networks plays an important role in power system security. The contribution of the so-called active distribution networks to system stability is expected to become highly significant.

Distribution system operators are required to manage and operate an extremely complex electricity grid with support from appropriate system control logics. By using both the grid's and consumers' flexibility potential to help solve constraints and maximise the utilisation of existing infrastructure, network performance can be optimised.

**A close cooperation between transmission and distribution system operators is important in order to address several operational challenges such as congestion management, voltage support, balancing challenges, and coordinated protection. This cooperation is critical for a smooth transformation of the pan-European electricity network over the coming years.**

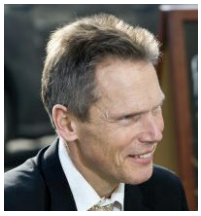
For the successful implementation of the energy transition, innovative concepts in system operation are required in parallel to the electrical grid reinforcement. With the flexibility potential of grid users and storage, as well as the intelligent use of power-flow-controlling equipment, a higher utilisation of the network can be achieved in order to integrate more renewable generation into the grid.

**DERlab and its member institutes have identified the afore-mentioned challenges and are active in many research projects, in which they investigate innovative system operation approaches, while aiming at maintaining the reliability and security of the power supply. These strategies employ tools with a high degree of automation, such as appropriate on- and off-line stability analysis tools as well as suitable grid control and protection schemes. These contribute to supporting system operators to enable efficient and secure electrical power system operation.**

This Activity Report presents the activities of DERlab and its members in form of international networking and knowledge exchange on the topic of smart grids operation, planning and control strategies. Furthermore, special emphasis is given to DERlab members' infrastructure developments and highlights in terms of research advancements since the previous issue of the Activity Report. Finally, this report introduces selected scientific publications released cooperatively by DERlab members during the reporting period 2018-2020.


DERlab Anniversary General Assembly, March 2018, Kassel (DE)

# Future of Research and Exploitation



**Patrick van Hove**

*Research policy in Smart Energy Systems*

Global warming has already reached 1°C above the pre-industrial level, due to past and current greenhouse gas emissions. This exposes people and ecosystems around the world to great challenges and risks both today, and in the future. Earlier this year, scientists voiced new evidence for the benefits of limiting global warming to the lowest possible levels. These warnings have reverberated throughout the younger generations, who view the effects of climate change as a threat to their future.

New European Commission president Ursula von der Leyen sees an opportunity for Europe to become the world's first climate neutral continent and has proposed Executive Vice-President Frans Timmermans to coordinate the European Green Deal. Europe wants to act first to benefit from the opportunities of the ecological transition, to disseminate its success and export knowledge, technologies and best practice around the world. In Europe, 70% of greenhouse gas emissions come from energy use in economic and domestic sectors. Various pathways to the decarbonisation of energy all point towards a growing reliance and importance on electricity. The European power sector has shown the potential for a lower carbon footprint and has pledged to become carbon neutral well before mid-century.

Europe has taken an early lead in deploying massive wind and solar power. Their integration has brought new challenges to the grids, such as fast ramps, less predictable power output and distance from the loads. Today's grids are also starting to exploit flexibility from demand response and EVs, coupling with other energy vectors, and in many cases, interfaces based on power electronics.

**DERlab addresses the key issues of interfacing new components in the power grids and validating the system behaviour of a grid built on these new solutions. From its start as a Network of Excellence project in 2005 and as an association in 2008, DERlab has grouped key laboratories in Europe and demonstrated the added value of the network.** Round-robin tests of inverters show that the results can be trusted at various sites. DERlab's portfolio of tests and services has been extended and now includes new technologies such as storage or EV chargers. Beyond the tests of devices, DERlab also presents HIL capabilities of its members, which enable component testing within a grid system. Having consolidated this range of testing capabilities in its Database of DER and Smart Grid Infrastructure, DERlab now demonstrates an extended overview of testing facilities all over the world.

The anniversary of the DERlab Association in 2018 marked 10 successful years of operation throughout which DERlab's research goals have been continuously in line with those of the European Union. This effort is reflected in a variety of success stories and milestones achieved within several FP7 and H2020 projects that spread over a range of topics: the integration of smart grid infrastructures through open transnational access programmes in SOPHIA RI, DER RI, ERIGrid and ERIGrid 2.0, enhancing PV distribution grid capacity in PV GRID, maintaining grid stability with DER support in DEA-Stabil, strengthening PV research in SOPHIA RI, enhancing holistic system testing in ERIGrid and ensuring control and stability in inverter dominated power systems in Grid Control 2.0. Committed to advancing power systems, DERlab supported the development of cost-effective tools for enabling grid flexibility in NOBEL GRID, the operation planning tool for TSOs and DSOs in INTERPLAN, blackstart capabilities in NETZ:KRAFT, and automation and energy management in EEPOS. Also, e-mobility has been addressed by DERlab through the development of business opportunities for interoperability assessment of EV integration in COTEVOS. Dedicated to smart grid advancement, DERlab contributed to recommendations for smart grid standardisation in STARGRID and the Web of Cells concept in ELECTRA IRP. Being the Operating Agent of ISGAN Annex 5 SIRFN since 2014, DERlab takes care to further strengthen international collaboration in the smart grid domain.

**The DERlab infrastructure and research are crucial for supporting the validation of components and the integration of the grids of tomorrow. Supporting the international exchange of expertise and researchers, DERlab fosters further development of the zero carbon energy system that Europe requires in the near decades.**

# A Global Approach to Smart Grids by Mission Innovation

**Luciano Martini**

*Italian co-lead for MI IC1*

Energy systems worldwide are facing a significant transformation. Many countries are facing challenges which, despite intrinsic differences in the system structure and energy mix, are very similar, e.g., seamless integration of high-share of variable renewable energy sources (vRES), such as wind and solar. It must be said that even though **the challenges are global, the technical solutions are local**. As a consequence, there is a need to develop a portfolio of suitable solutions to be tailored to the specific grid constrains and/or geographical context.

In light of this, I believe there are a number of ways in which the worldwide development and deployment of smart grids can be accelerated: the sharing of both best practice and exploitable results for replication, identifying and filling gaps in knowledge and available tools and improving. It is clear from this that international co-operation is a vital factor in realising this quicker implementation of smart grid solutions.

Accelerating the clean energy innovation is the aim of the global initiative Mission Innovation (MI), launched in 2015 in Paris at COP21. The initiative, in boosting research, development and innovation, has identified eight key challenges covering every aspect of the energy system. In particular, power system innovation and integration of renewable energy sources into the electrical grid are within the scope of the MI Innovation Challenge 1 (IC1) on Smart Grids.

MI IC1 on Smart Grids, officially launched in 2017 and co-led by China, India and Italy, at present involves 20 countries and the European Union, represented by the European Commission.


1st MI-IC1 Industry Workshop, Rome (IT), November 2018

The main objective of IC1 is to accelerate the development and demonstration of smart grid technologies in a variety of grid applications. These include the robust, efficient and reliable operation of regional, distribution and microgrids in diverse geographical conditions as well as facilitating cost effective uptake of renewable energy.

IC1 work started with the identification and selection of the smart grids R&D topics, which the IC1 members agreed to be the most important and urgent to focus the research effort on. As a result, the following six R&D joint Tasks were defined and launched: Storage integration, Demand response, Regional electricity highways, Flexibility options, New grid control architectures, and Power electronics.

Another important activity launched by IC1 is the **Smart Grids Innovation Accelerator (SGIA)**, an open platform gathering information, data, tools, factsheets, results, best practices and successful project outcomes in the field of smart grids with the specific aim to be replicated and adopted broadly. Enabling the sharing of technical results and best practices, the SGIA platform will catalyse the joint efforts of the public and private sectors towards IC1 goals, thus accelerating the development and deployment of innovative smart grids technologies worldwide.

**I strongly believe the power of MI IC1 resides in a balanced mix of expertise. Joining forces and effectively involving the proper combination of different stakeholders from the public and private sector, the initiative is on the right track to accelerate the implementation of smart grids projects and initiatives.**

MISSION INNOVATION

www.mission-innovation.net

# ETIP SNET Transforming the Future Energy System

**Prof. Nikos Hatziargyriou**

*Co-Chair ETIP SNET as of 2019*
*Chairperson ETIP SNET January 2018 - July 2019*

The European Technology & Innovation Platforms (ETIPs) have been created by the European Commission in the framework of the new Integrated Roadmap Strategic Energy Technology Plan (SET Plan) by bringing together a multitude of stakeholders and experts from the energy sector.

Since 2016, the key energy system players in Europe, represented through their EU associations, platforms and national stakeholders, started a strong and unique cooperation under the umbrella of ETIP SNET – The European Technology and Innovation Platform Smart Networks for Energy Transition. **The role of ETIP SNET is to guide research and development in order to support Europe's energy transition with innovation for the transmission and distribution systems. These systems form the technical and market platforms where clean electricity generation, empowered customers, storage technologies, smarter grids and interfaces to gas, heat and transport networks make the energy transition happen in secure and affordable ways.**

In June 2018, ETIP SNET launched its Vision 2050 for "a low-carbon, secure, reliable, resilient, accessible, cost-efficient, and market-based pan-European integrated energy system supplying the entire society and paving the way for a fully carbon-neutral circular economy by the year 2050, while maintaining and extending global industrial leadership in energy systems during the energy transition." The report forms the basis for defining the specifications for further research and innovation needs for the transition towards Europe's energy systems of the future. Hence, its purpose is to inspire all stakeholders to discover the RD&I challenges associated with a 2050 low-carbon, fully-integrated, and circular pan-European energy system with the electricity system as its backbone.

The Vision 2050 goes beyond prior smart grid innovation visions through its clear low-carbon commitment in line with the Governance Regulation of the EU clean energy package. This holistic view will drive integration of electricity, gas, heating/cooling and mobility systems and markets, with smart and strong electricity networks at the centre.

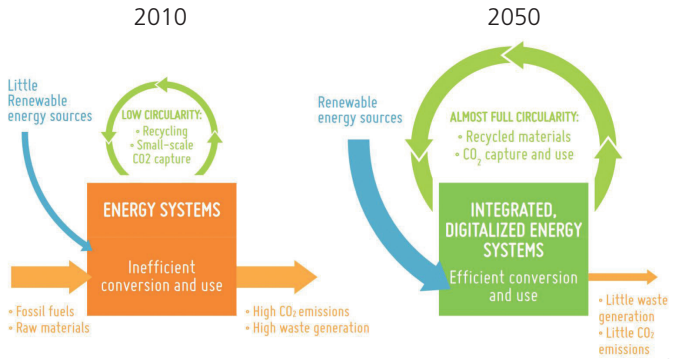
**As described in the Vision 2050, serving Europe's clean energy needs will require major investments for the large-scale deployment of energy conversion and storage devices, the upgrade and extension of the energy networks, and the use of digital solutions. While policy makers, industry and researchers need to lead the way and lay down the foundations for the transition towards a cleaner energy system, the citizen is the fundamental player that will make this transition possible.**

Citizens have the potential to play a key role in Europe's energy transition and change the course of current climate change trends. Informed of the latest technological developments, they have the power to select the technologies that will not only meet their energy needs in a more efficient and cost-effective way, but also determine the greening of the energy system as a whole.

For this reason ETIP SNET also aims to inform and educate citizens through its "Energy Stories", designed to bring successful applications in energy transition technologies, often developed through public funding, closer to the citizen, highlighting whenever possible the direct benefits of the latest technologies to the energy consumer.

Currently, ETIP SNET is developing a new Research and Innovation Roadmap (2020-2030), which will incorporate the latest feedback from the upcoming ETIP SNET workshops and monitored projects across Europe. **While the Vision 2050 aims to inspire energy users in taking decisions in the transition to a cleaner, fully integrated pan-European energy system, the new roadmap will illustrate the framework with the features and the related RD&I activities to be deployed before 2030.**

DERlab is active in ETIP SNET WGs on flexible generation and innovation implementation in the business environment. Among other activities, DERlab supports the analysis of innovation projects with its experience in RI coordination for successful implementation of innovative solutions and will be involved in the consultation process regarding the ETIP SNET Roadmap 2020-2030.




From the past quasi-linear to the circular economy in 2050

ETIP SNET
PLAN. INNOVATE. ENGAGE.

www.etip-snet.eu

# SIRFN Advancing Grid Integration of Renewable Energy with Results Dissemination in EERA, SIRFN and ERIGrid

**Jay Johnson**
*Sandia National Laboratories*
*2014-2019: Lead of SIRFN Task Test Protocols for Advanced DER Interoperability Functions*

Countries around the world are facing similar challenges when installing renewable energy systems in their power grids and its is evident that multinational collaboration could help to accelerate their integration. By working together, the SIRFN team is compiling a network of experts to all contribute their individual expertise, to develop a versatile research platform for use in laboratories worldwide.

**The Smart Grid International Research Facility Network (SIRFN) - Annex 5 of ISGAN - gives the participating countries the ability to evaluate pre-competitive technologies and systems in a wide range of smart grid implementation use cases and networks (with different grid voltages and frequencies) using common testing procedures. Research within each individual member country builds on and supplements a common test platform at the other partner nations. Data from these tests is made publicly available to the smart grid community to accelerate the development of smart grid technologies and systems, and support national and international development of interconnection and interoperability standards.**

This effort incorporates nearly a dozen SIRFN laboratories - many of whom are also DERlab members - into a multinational research team focused on DER interoperability and advanced grid-support functions. The group has published several joint conference and journal papers on the results of the laboratory experiments and associated recommendations to national certification standards.

DER equipped with standardised, interoperable, grid-support functionality have the capability to provide a range of services for power system operators. These capabilities were recently codified in multiple, national and international standards, including IEEE Std. 1547-2018. Standardised test procedures - such as those in IEEE Std. 1547.1- are now being updated to validate the new interoperability and electrical functionality of DER devices. Unfortunately, test standards are rarely fully exercised to identify mistakes, redundancies, or implementation challenges prior to publication. **To improve these test standards at the draft stage, an international community of research laboratories within SIRFN have developed open-source test scripts to execute the draft certification protocols. Laboratories in North America, Europe, and Asia conducted experiments with four, three-phase DER devices using the draft IEEE 1547.1 protocols, including tests for constant-power-factor, volt-var, volt-watt, and frequency-watt.** The experiments were conducted using the System Validation Platform (SVP), a versatile, open-source DER testing and certification platform that automatically executes test procedures by communicating to the device under test, grid simulator, PV simulator, and data acquisition system using Python scripts. Based on the results, the SIRFN team fed recommendations back to the standards development organisation to improve the draft test protocol during the balloting process. The results were presented at the 2019 EU PVSEC conference.

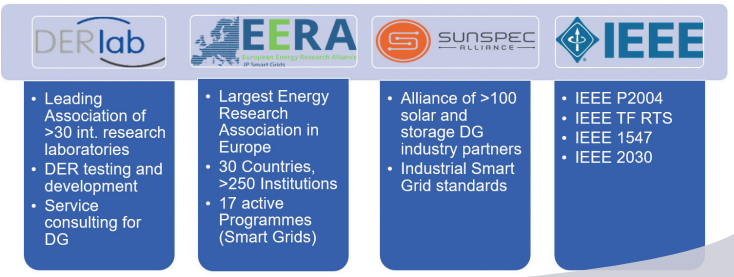
Fostering efficient dissemination of research results, in 2019 DERlab incorporated ERIGrid's Holistic Test Description in the SIRFN Power System Testing Task. The same year, DERlab involved DERlab members who were not represented in ISGAN as external observers in SIRFN in order to integrate their expertise and scientific contribution. With the corresponding activities already in progress, SIRFN research will benefit from this collaboration.

At the joint workshop in Montreux (CH) on 30 September 2019, organised by SIRFN, ISGAN, Clean Energy Ministerial, DERlab, EERA JP Smart Grids, Mission Innovation and International Energy Agency (IEA) Energy Technology Network, it was decided that DERlab will restructure, update and combine topics related to energy system digitisation within SIRFN and EERA JP Smart Grids in order to leverage the expertise of all networks. **DERlab will thus interface between networks and propose new research to pave the way to holistic and effective collaboration.**

SIRFN
ISGAN Annex 5

CLEAN ENERGY MINISTERIAL
iea Energy Technology Network
ISGAN

www.sirfn.net




SIRFN collaboration with key networks

# Global Smart Grids Infrastructure in DERlab Database

Be it for ensuring the reliability of the existing equipment, for further development of equipment functionalities or for testing new methodologies in research projects, researchers and developers in the smart grid and DER field need laboratories and testing facilities for experiments, demonstration pilots and other research purposes. **In order to connect existing labs with researchers and potential customers, DERlab offers a unique service - the DERlab Database of DER and Smart Grid Research Infrastructure.** Currently, the directory holds information on over 220 laboratories, testing capabilities and services, spanning over 50 institutes worldwide.

**In order to provide an up-to-date overview on the existing research infrastructures across the world, DERlab strives to expand the database on an ongoing basis, encouraging all institutes active in the field of DER and smart grids to submit information on their facilities.** The database is open for entries at **infrastructure.der-lab.net/add-your-ri-database** and provides all companies and institutes the chance to present extensive information about their facilities for potential customers, such as:

- Static and mobile equipment
- Power range
- Simulation and optimisation tools
- Offered testing services within the laboratory
- Quality management and standards compliance of the offered testing services

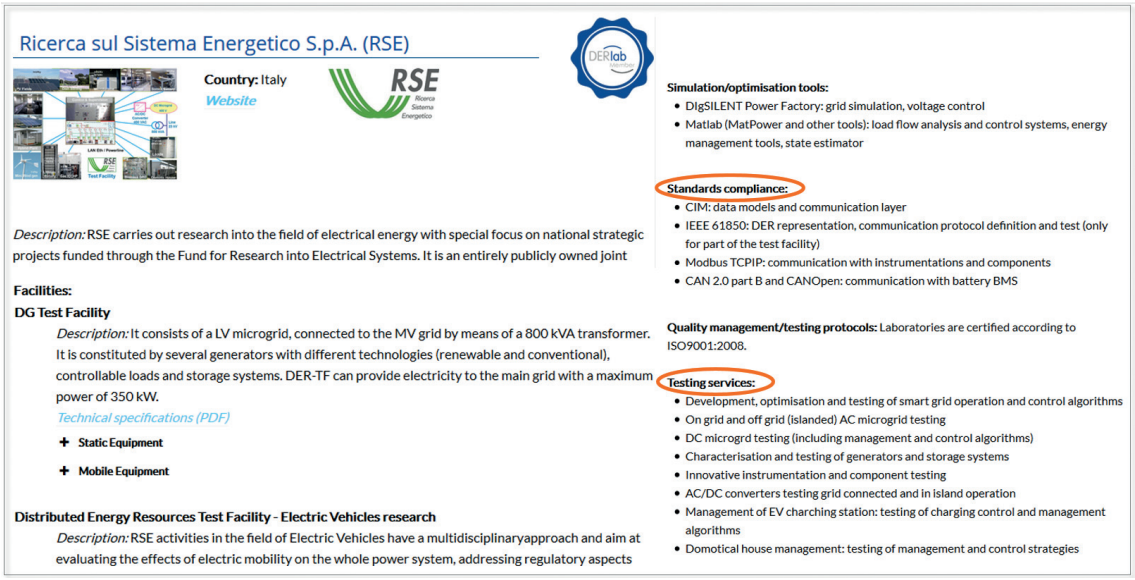
Utilised by the broad international network of DERlab and smart grid stakeholders worldwide, the database ensures the exposure of any given facility in the DER and smart grids community. Thanks to the detailed functionalities, companies and stakeholders seeking to commission testing or consulting services can easily find specific services offered by the variety of facilities represented in the database. PV system labs, PHIL simulation environments and microgrid configurations are just a broad selection of examples of research infrastructures that are included in the database.

With the support of ETIP SNET Working Groups, DERlab plans to extend the database with new facilities and labs. This development will connect even more infrastructures with companies and researchers seeking to perform advanced testing in the field of renewable energy and smart grids. Furthermore, in 2020 DERlab will include open-source resources developed at the represented testing infrastructures. This improvement will benefit the effective exploitation of research results.

Database of DER and Smart Grid Research Infrastructure

Maintained by DERlab since 2012, the DERlab **Database of DER and Smart Grid Research Infrastructure** openly provides coordinated information on smart grid and DER laboratories, testing facilities and similar competencies. The database is strongly supported by the ISGAN Annex 5 SIRFN and the EU-funded projects ERIGrid, ELECTRA IRP, COTEVOS, SOPHIA. Starting from January 2019, the PANTERA project is also supporting the database and contributing to its extension.

**infrastructure.der-lab.net**



Ricerca sul Sistema Energetico S.p.A. (RSE)

**Country:** Italy
*Website*

*Description:* RSE carries out research into the field of electrical energy with special focus on national strategic projects funded through the Fund for Research into Electrical Systems. It is an entirely publicly owned joint

**Facilities:**

**DG Test Facility**

*Description:* It consists of a LV microgrid, connected to the MV grid by means of a 800 kVA transformer. It is constituted by several generators with different technologies (renewable and conventional), controllable loads and storage systems. DER-TF can provide electricity to the main grid with a maximum power of 350 kW.

*Technical specifications (PDF)*

+ **Static Equipment**
+ **Mobile Equipment**

**Distributed Energy Resources Test Facility - Electric Vehicles research**

*Description:* RSE activities in the field of Electric Vehicles have a multidisciplinaryapproach and aim at evaluating the effects of electric mobility on the whole power system, addressing regulatory aspects

**Simulation/optimisation tools:**

- DIgSILENT Power Factory: grid simulation, voltage control
- Matlab (MatPower and other tools): load flow analysis and control systems, energy management tools, state estimator

**Standards compliance:**

- CIM: data models and communication layer
- IEEE 61850: DER representation, communication protocol definition and test (only for part of the test facility)
- Modbus TCPIP: communication with instrumentations and components
- CAN 2.0 part B and CANOpen: communication with battery BMS

**Quality management/testing protocols:** Laboratories are certified according to ISO9001:2008.

**Testing services:**

- Development, optimisation and testing of smart grid operation and control algorithms
- On grid and off grid (islanded) AC microgrid testing
- DC microgrd testing (including management and control algorithms)
- Characterisation and testing of generators and storage systems
- Innovative instrumentation and component testing
- AC/DC converters testing grid connected and in island operation
- Management of EV charching station: testing of charging control and management algorithms
- Domotical house management: testing of management and control strategies

# ERIGrid's Holistic Approach for Validating Smart Grids

The ERIGrid project addresses system validation for smart grids and the development of common methods, concepts and procedures by integrating eighteen European research centres and providing free open access to their outstanding research infrastructures.

Obtained with the support of the DERlab member network, the information about the current testing and evaluation methods and procedures, as well as research infrastructure needs and requirements, was thoroughly examined by the ERIGrid consortium. **Based on this analysis and aiming for a holistic, cyber-physical systems based approach, the ERIGrid consortium designed the Holistic Testing Description (HTD) method to enhance the necessary research services for analysing, validating and testing smart grid configurations. With the ERIGrid method, research laboratories can combine their unique qualities to devise meaningful system tests. The approach applies to all scales of experiments, combinations of physical and simulated testbeds, and many engineering disciplines.**

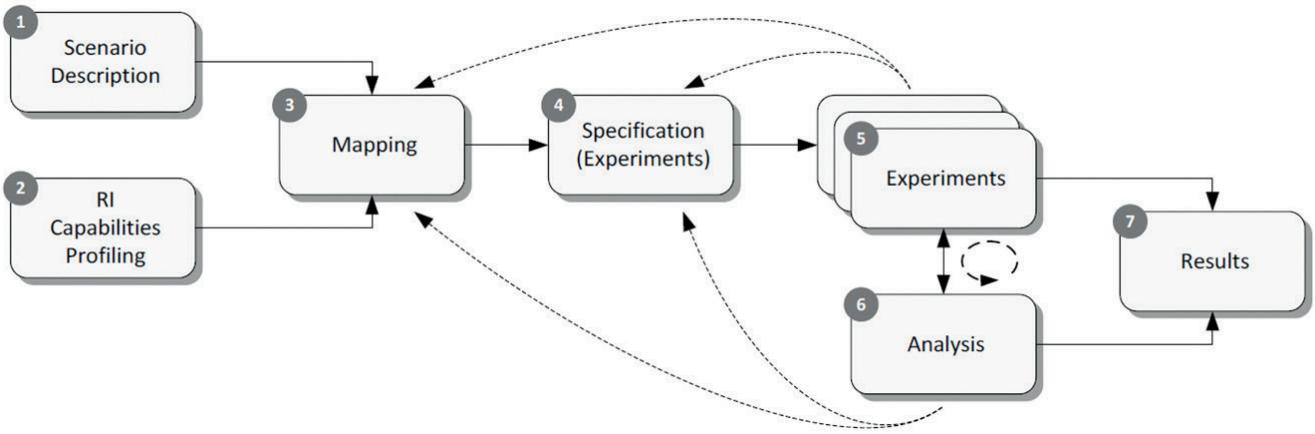
Furthermore, ERIGrid has developed a number of smart grid validation solutions, such as laboratory-based methods and HIL techniques, co-simulation methods and tools, and a laboratory coupling approach. ERIGrid has also produced a variety of training materials and tools, such as real-time simulation for laboratory education, and remote and virtual laboratory access. **All ERIGrid's open-access resources are available on the project website, including the white book "European Guide to Power System Testing: The ERIGrid Holistic Approach for Evaluating Complex Smart Grid Configurations".**

Within the frame of its Trans-national Access (TA) programme, ERIGrid has provided open access to 19 laboratories of the ERIGrid consortium. **Through this opportunity, Europe's leading smart grid and DER testing facilities opened their doors to external users from research, academia and industry for their own experimental research – free of charge. Nearly one hundred of user groups from academia, research, and SMEs received funding through the ERIGrid TA. They carried out their experimental projects supporting component characterisation, small-scale and large-scale systems validation. Within the frame of the successor project ERIGrid 2.0, the TA programme will continue to support engineers with access to high-level scientific infrastructures in their research endeavours.**

Connecting European Smart Grid Infrastructures

**ERIGrid**: European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Rollout
**Duration**:
November 2015 – April 2020
**Funding**: RIA - Research and Innovation Action
**Partners**: 18 partners, including DERlab Office

**www.erigrid.eu**




HTD validation approach

# ERIGrid 2.0: Free Access to European Research Infrastructures

Based on the results from the ERIGrid project, the successor project ERIGrid 2.0 will expand the research services and tools of research infrastructures for validating smart energy networks with the electric power grid as the main backbone. Committed to the holistic and cyber-physical systems-based validation approach, ERIGrid 2.0 will foster system-level support and education for industrial and academic researchers in power and energy systems research and technology development.

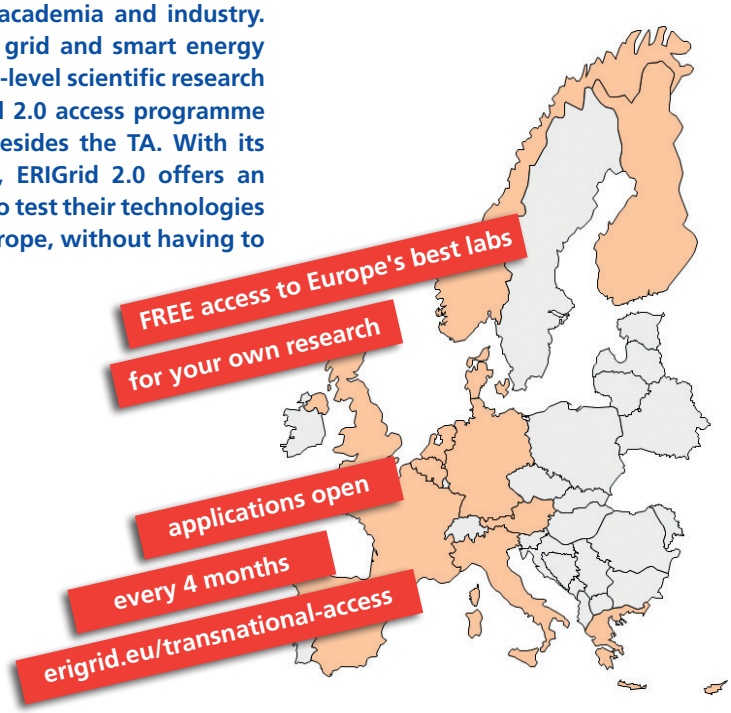
With the DERlab member network significantly represented in the ERIGrid 2.0 consortium, the project will draw on the longstanding experience of DERlab members regarding the validation of the smart energy networks. In particular, ERIGrid 2.0 will collect and analyse information on the state-of-the-art methods and requirements for lab-based validation and testing. Furthermore, DERlab members will introduce several reference smart grids scenarios and test cases to the project in order to evaluate the methodologies developed by ERIGrid 2.0.

Through a number of training activities and the TA programme, ERIGrid 2.0 will connect and support professionals working on power systems and ICT. Several DERlab members in the project, including AIT, CRES, DTU, ICCS-NTUA, Fraunhofer IEE, RWTH Aachen, DNV GL, CEA, RSE, TECNALA, VTT and the University of Strathclyde, are actively involved in developing and producing valuable resources for engineers, researchers and students in the field of smart grids and smart energy systems.

**Just as with the precursor project, ERIGrid 2.0 will open access to 29 world-leading testing facilities of the project consortium for research, academia and industry. This opportunity is particularly valuable for those smart grid and smart energy systems actors who cannot otherwise afford access to high-level scientific research infrastructures. One of the exceptional aspects of ERIGrid 2.0 access programme is the provision of Virtual Access (VA) to laboratories, besides the TA. With its VA being the only programme of this kind worldwide, ERIGrid 2.0 offers an unparalleled opportunity for researchers across the globe to test their technologies and solutions free of charge, in the best laboratories in Europe, without having to travel to their location.**

**ERIGrid 2.0**: European Research Infrastructure supporting Smart Grid and Smart Energy Systems Research, Technology Development, Validation and Roll Out – Second Edition
**Duration**: April 2020 - September 2024
**Funding**: RIA - Research and Innovation Action
**Partners**: 20 partners, including DERlab Office

**www.erigrid.eu**





Nearly 90 research teams from all over the world gained free lab access to the testing facilities of ERIGrid

# PANTERA: Boosting R&I in the fields of smart grids, storage and local energy systems

**PANTERA**: Pan European Technology Energy Research Approach
**Duration**:
January 2019 – December 2022
**Funding**: CSA - Coordination and support action; H2020 grant agreement no. 824389
**Partners**: 9 partners, including DERlab Office

**www.pantera-platform.eu**

**PANTERA project aims at setting up a European forum composed of Research & Innovation stakeholders active in the fields of smart grids, storage and local energy systems, including policymakers, standardisation bodies and experts in both research and academia representing the EU energy system.**

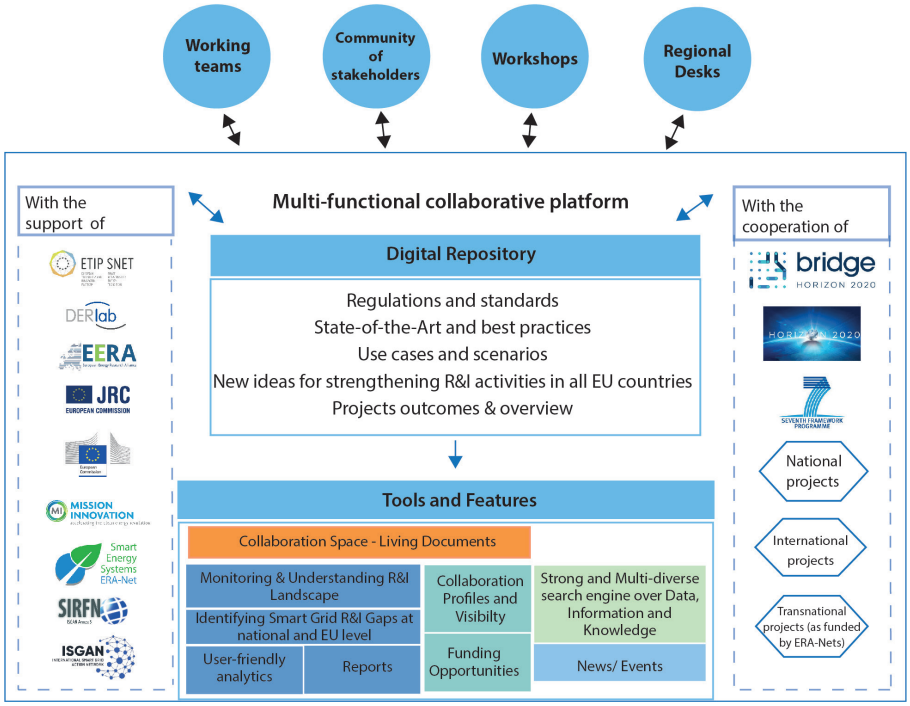
PANTERA established a multi-functional collaboration platform as a tool for the collection of real data and results from ongoing projects. This open access platform contains highly relevant data for anyone developing case studies of exploitable results, scenario building, conducting local energy system analysis, and more. The platform is continuously updated with results from relevant projects so that all stakeholders in the energy domain benefit from the data, including information on:

- Overview, outcomes and publications from relevant energy projects
- Regulations and standards
- State-of-the-art and best practices
- Use cases and scenarios
- New ideas for strengthening R&I in EU countries

PANTERA platform will interact with other energy platforms and initiatives such as EXPERA, ETIP SNET, BRIDGE, and others.

Main impacts:

- Build a pan-European research & innovation community in the field of smart grids.
- Bridge the gaps between the member states in the research & innovation energy field and incentivise investments in smart grid.
- Establish a sustainable multi-functional platform for the EU research & innovation family in the field of smart energy systems and technologies, in support of the energy transition & low carbon economy.




DERlab members are playing a crucial role in the PANTERA project, contributing through:

- Identifying research and innovation opportunities
- Sharing project results on the pan European level
- Providing input for the PANTERA platform
- Giving feedback to PANTERA activities through continuous cooperation with the project

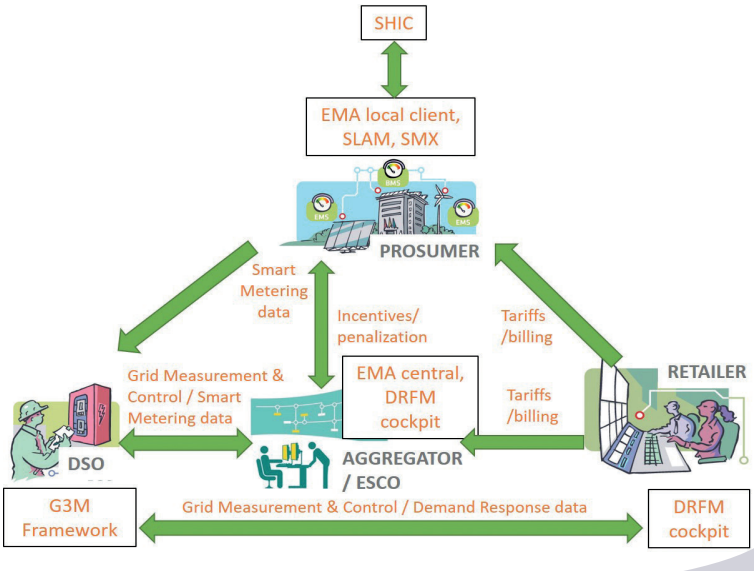
Any expert from the field of smart grids, storage and local energy systems can join PANTERA project as a stakeholder. Please visit **pantera-platform.eu/stakeholders**

# NOBEL GRID Success Story: From Lab to Business

**NOBEL GRID developed, deployed and evaluated advanced tools and ICT services for DSOs and electric cooperatives, thus enabling active consumer involvement and market flexibility.**

**Focusing on residential customers, NOBEL GRID involved grid operators, energy service companies, energy providers and retailers, renewable cooperatives and aggregators. All the energy system actors are supposed to interact and actively use the flexibilities of prosumer-side electric loads and generators for optimising their business on the unbundled market.** Technically, the actors are supported by tools developed in the project:

- A low-cost smart meter extension (SMX) for the prosumers serves as a pivot point for data transmission, handles wide-area networks access to the prosumer's local area components, serves as a firewall for the prosumer, and allows for extension with third-party smart home applications.
- Smart Low-Cost Advanced Meter (SLAM) is an advanced multi-function digital single-phase smart meter class B in active energy and class 2 in reactive energy.
- A Grid Management and Maintenance Master Framework (G3M) for grid operators allows for detailed supervision and control of the energy system all the way down to the low-voltage level. It integrates into and extends existing SCADA systems.
- A Demand Response Flexible Market Cockpit (DRFM) exposes the flexibility provided by controllable loads and generators at the customer premises towards aggregators, ESCOs, retailers, and grid operators.
- An Energy Management and Analysis App (EMA App) for ESCOs and prosumers visualises and analyses the client's energy usage, and also allows advanced functions like neighbourhood trading of energy.




NOBEL GRID concept

**NOBEL GRID**: New Cost Efficient Business Models for Flexible Smart Grids
**Duration**:
January 2015 – June 2018
**Funding**: H2020 grant agreement no. 646184, Integrating Activity (IA)
**Partners**: 21 partners, including DERlab Office

**www.nobelgrid.eu**

**Close-to-market solutions, usage of modern standards and methodologies, and cost efficiency due to the usage of open source solutions are key factors that made NOBEL GRID stand out.**

The project results, including high-level use cases, were tested not only in partners' laboratories but also in real life at six pilot sites all across Europe: Alginet (ES), Manchester (UK), Flanders (BE), Terni (IT), Meltemi (EL) and Bucharest (RO).

NOBEL GRID has released multiple publications, developed a smart grid architecture definition based on SGAM, and supported parts of the OGEMA release 2.1.0. and OGEMA SDK, both developed by Fraunhofer IEE and DERlab Office (**ogema.org**).

NOBEL GRID consortium at the final event

# INDORSE: International Cluster on Inverter Dominated Power Systems

INDORSE
International
Project cluster

**INDORSE**: International Cluster on Inverter Dominated Power Systems
**Partners**: numerous stakeholders worldwide, including DERlab Office

**www.indorse-cluster.net**

The power quality and reliability of today's power systems is mostly based on synchronous generators. In order to operate the future power systems securely and stably with very high shares of inverters, we need to develop appropriate control algorithms and operation procedures. Inverter systems can partially reproduce physical properties similar to those of synchronous generators, and suitable testing procedures will be developed in the ongoing research.

The need for scientific exchange on the topic led to the kick-off of an international research cluster "Grid control for inverter-dominated power systems" during the 8th International Conference on the Integration of Renewable and Distributed Energy Resources (IRED) on 17 October 2018 in Vienna (AT). With over sixty experts from Europe, North America and Asia, the workshop established connections to a wide range of relevant domains, including system operation, industries, research and academia.

Having formed the international project cluster on Inverter Dominated Power Systems (INDORSE) aiming for harmonised grid codes and testing procedures, the partners pursue the objective to foster knowledge exchange, support research towards pre-standardisation activities and accelerate the implementation in relevant projects.

In particular, INDORSE addresses the following topics:

- System stability aspects
- Power quality
- Grid connection rules (grid codes and requirements)
- Protection schemes
- Testing procedures
- Modelling in power system studies

INDORSE kick-off at IRED 2018 in Vienna (AT)

# Grid Control 2.0: Control and Stability in Inverter Dominated Power Systems

It is anticipated in the near future that, in order to reduce global greenhouse gas emissions, conventional power plants will be superseded by decentralised generation, with a large share of that coming from renewable energy sources. **The objective of the Grid Control 2.0 consortium is to develop new technologies in which the electric grid will be mainly operated from inverter-connected generators, without compromising the safety and stability of the grid. To attain the frequency and voltage stability from the grid inverters, it should possess similar properties like that of synchronous generators. The project strives to contribute to grid-forming inverters replacing today's conventional power plants providing inertia.**

Grid codes set the minimum technical requirements for connecting renewable energy resources and battery systems, which were recently harmonised at all voltage levels. Project results will also help in further improving the mentioned technical guidelines.

DERlab is developing evaluation criteria for existing control approaches of grid-forming inverters and existing inverter control aspects. Coordinating with DERlab members, who have expertise in advanced laboratory testing methods and power systems testing, DERlab enhances information exchange and project dissemination, and will be actively providing further suggestions for improving the technical guidelines and grid codes. Being the Operating Agent of IEA ISGAN Annex 5 SIRFN and actively involved in other key initiatives, DERlab´s strong international network supports the dissemination of results and exchange of expert opinions with the project.

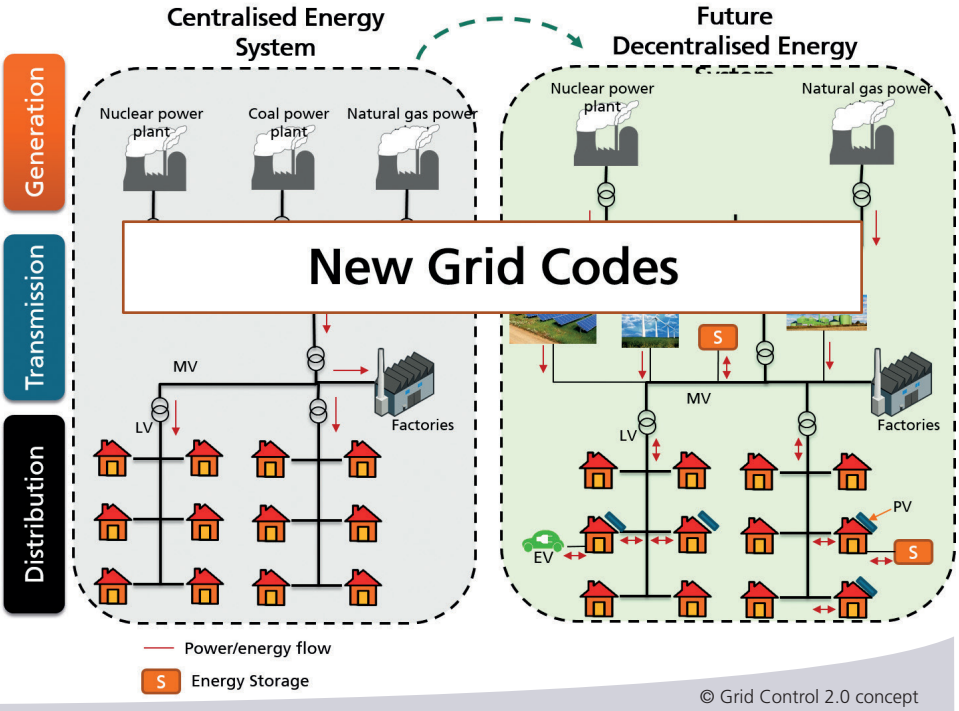
Fraunhofer IEE, in collaboration with elenia (TU Braunschweig), University of Kassel, DERlab and SMA, is involved in studies on:

- grid integration and its stability
- developing inverter controls
- field tests and in-laboratory testing
- preparation and implementation of grid codes

Netzregelung 2.0

**Grid Control 2.0 (Netzregelung 2.0)**: Control and Stability in Inverter Dominated Power Systems
**Duration**: December 2017 - November 2021
**Funding**: Federal Ministry for Economic Affairs and Energy
**Partners**: 14 partners, including DERlab Office

Fraunhofer IEE is also performing studies on the requirements of German power supply. Elenia will be focusing on research questions related to power plants of smaller capacity in LV and MV. The new inverter control concepts will also be validated by elenia.




© Grid Control 2.0 concept

# Reinforcing Blackstart Capabilities in NETZ:KRAFT

**NETZ:KRAFT**: Grid restoration in consideration of future power plant structures (Netzwiederaufbau unter Berücksichtigung zukünftiger Kraftwerkstrukturen)
**Duration**: January 2015 – June 2018
**Funding**: Federal Ministry for Economic Affairs and Energy (BMWi)
**Partners**: 20 partners, including DERlab Office

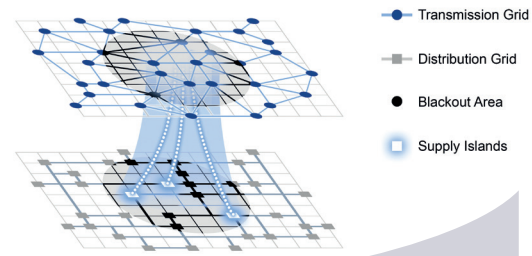
**www.netz-kraft-projekt.de**

The NETZ:KRAFT project analyses the possibilities offered by distributed and renewable energy resources to contribute to the restoration of the power system after blackouts. Therefore the project combines two different approaches:
1. top-down approach: further development of the existing grid restoration processes at the transmission grid level, considering the increasing amount of distributed energy resources.
2. bottom-up approach: active usage of distributed energy resources in supply islands of distributions system operators to shorten the outage of the grid.

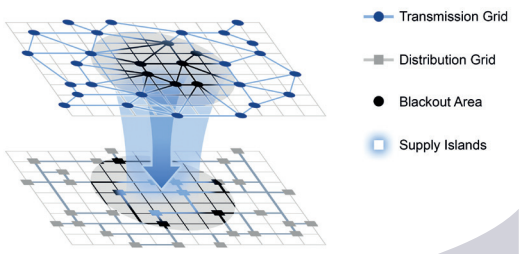
In addition to the technological aspects, the project also deals with the coordination between system operators. NETZ:KRAFT brings relevant stakeholders – DSOs, TSOs, manufacturers, researchers – together to deal with the challenge of power system restoration in future scenarios.

**DERlab supported the project in the status determination of technology trends, terms and technical requirements of the grid restoration process, as well as in the definition of the scenarios. DERlab played an important role in organising information exchange, in the presentation of the project's results and recommendations on the European and international levels. Moreover, DERlab was involved in the standardisation environment providing and reviewing existing standards in the context of grid restoration process. Thereby, a detailed basis for discussion between network operators, standardisation institutions and regulatory authorities in cooperation with the manufacturers was provided.**

In the NETZ:KRAFT project, Fraunhofer IEE implemented and validated the Nordic Test System in DIgSILENT PowerFactory, which is now openly available online through the IEEE PES Power System Dynamic Performance Committee. The Nordic test system is a network model proposed by CIGRE Task Force 38-02-08 in 1995 in order to assess the performance of simulation tools and provide researchers with benchmarks to develop the Long-Term Dynamics field. The system is not limited to long-term phenomena and its applicability to short-term dynamics such as transient stability and small-signal oscillatory angle stability is also recognised.



Bottom-up strategy in grid restoration



Top-down strategy in grid restoration

# ELECTRA IRP Introducing Web of Cell Concept

The ELECTRA IRP project addressed the aspect of validation and testing of frequency and voltage control in the future grid based on the SGAM. In this context, the project developed and validated the Web of Cell (WoC) concept, which is a novel control scheme for real-time frequency, balance and voltage control for the future (2035+) power system. The concept utilises decentralised real-time control where the power system is divided into small cells, and the emerging issues are dealt with by system operators in each cell in a decentralised manner. In this context, a cell is defined by ELECTRA IRP as a group of interconnected loads, DER and storage units within well-defined grid boundaries, that is able to maintain an agreed power exchange at its boundaries.

The WoC concept aims to provide a secure and stable distribution system control of the power network. In the context of ELECTRA IRP project, different controllers were developed in order to restore frequency and voltage to the nominal values:

- Balance Restoration control (BRC) allows cells to collaboratively restore the system balance.
- Frequency Containment Control (FCC) acts globally and collaboratively to support BRC control.
- Balance Steering Control (BSC) implements a peer-to-peer/bilateral explicit imbalance netting scheme.
- Inertia Response Power Control (IRPC) activates synthetic inertia in each cell to build up relatively constant inertia in the power system as a whole.
- Post Primary Voltage Control (PPVC) was developed to combine today's secondary and tertiary voltage controls.

In order to integrate European testing infrastructures and research efforts, ELECTRA IRP provided free access to laboratories of project members within its ELECTRA REX programme. Thanks to this effort, a number of external researchers were able to perform their experiments at ELECTRA IRP facilities, including those of 12 DERlab members.

**ELECTRA IRP**: European Liaison on Electricity Committed Towards long-term Research Activity Integrated Research Programme
**Duration**:
December 2013 – November 2017
**Funding**: FP7-ENERGY
**Partners**: 21 partners, including DERlab

**www.electrairp.eu**


ELECTRA IRP final event,
San Donato Milanese (IT), February 2018

# INTERPLAN: Integrated Operation Planning Tool towards the pan-European Network

**INTERPLAN aims to provide an integrated operation planning tool for the pan-European electricity network, with a focus on the TSO-DSO interfaces, to support the EU in reaching its expected low-carbon targets.**

**INTERPLAN:** Integrated Operation Planning Tool towards the pan-European Network
**Duration**:
November 2017 – October 2020
**Funding**: RIA - Research and Innovation action
**Partners**: 6 partners, including DERlab Office

**www.interplan-project.eu**

## Objectives

**INTERPLAN is set up to reach the ambitious goal of designing the energy system from 2020 up to 2050, implementing the crucial changes that are required in power systems, for instance integrating significant renewable energy systems.**

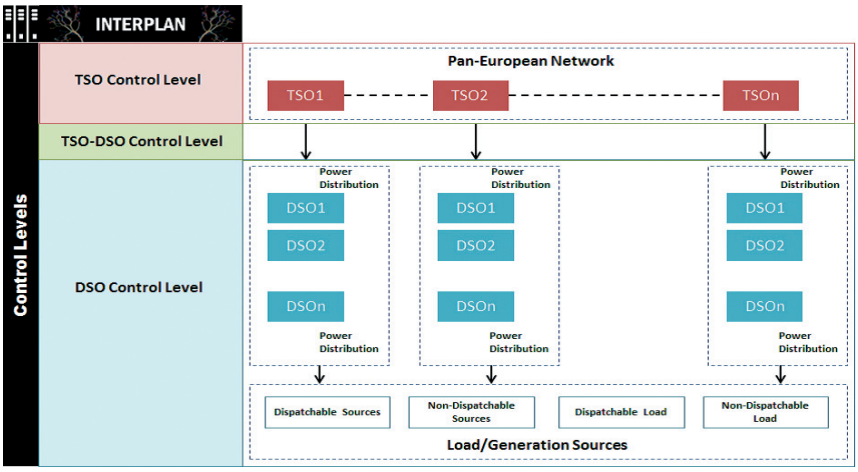
INTERPLAN brings its contribution in supporting the long-run European decarbonised energy targets by:

- Ensuring reliable control over the power grid at all voltage levels
- Exploiting the potentials throughout the grid
- Ensuring the pan-European grid to host larger quantities of RES

**Research and Innovation Objectives**

- Analysis of main grid operation challenges
- Grid equivalenting and definition of use cases
- Development of network models
- Development of an operation planning tool for the future EU grid

The ongoing deployment of the pan–European electricity system introduces new challenges for the networks. The characteristic fluctuating output of many distributed renewable energy resources changes the entire behaviour of the power system, making it more complex to constantly balance generation and load.Therefore, a closer cooperation among TSOs and DSOs is needed to address several operational challenges such as congestion of transmission-distribution interface, congestion of transmission and distribution lines, voltage quality issues, etc. Taking into consideration the increase of renewable energy resources, novel solutions are needed to support the future operation of the EU electricity system in order to increase the security of the electricity supply.




**INTERPLAN aims to develop a tool for grid operation planning based on the implementation of innovative control approaches and designed by paying particular attention to aspects such as flexible possibilities coming from storage and demand response. Novel control strategies and operational approaches will be investigated in order to ensure the security of supply and flexibility of the interconnected EU electricity grids, based on a close cooperation among TSOs and DSOs.**

A methodology for proper representation of a "clustered" model of the pan-European network has been developed, aiming to generate grid equivalents as a growing library able to cover all the relevant system connection possibilities occurring in the real grid, by addressing operational issues at transmission, distribution and TSOs-DSOs interfaces. Its versatility in the concept of grid equivalents will allow an accurate analysis of the complex network, by considering local active elements in the grid.

The selection of a top-down approach has inspired the development of an integrated tool for planning exercises that span from high voltage to low voltage, and that enable structured assessment spanning long-term planning to operational controllers.

# Expected impacts and role of the DERlab network in INTERPLAN

INTERPLAN considers planning, development and operational issues presented by the future integrated grid, with a view to addressing the challenges of integrating intermittent RES technologies, storage, and flexible aggregated demand response. In this respect, **INTERPLAN responds to the strategic objectives of the EU in reducing emissions by 40% by 2030 and achieving a 27% RES target in the final energy consumption over the same period.**

INTERPLAN moves away from the conventional radial design of the grid and approaches planning, development and operation from a technology-neutral view, allowing active contributions throughout the network in line with ongoing policy developments. **The versatility of the INTERPLAN tool lies in the concept of grid clustering and equivalenting, allowing accurate analysis of the complex pan-European network without losing the vital contribution of local active elements, thus utilising the benefits of distributed resources in an optimal pan-European perspective.**

In addition to the points mentioned above, INTERPLAN is expected to contribute to:

- Optimised grid planning and design at European level, maximising the capacity of the grid to host variable renewables and take full advantage of a pan-European grid for stability and security.
- Safe, secure, efficient and coherent data handling, enabling more cross-border trading and real-time balancing.
- Enabling new flexibility services to the grid associated with new business opportunities, offering the access to cheaper energy for the consumers and maximising the social welfare.
- Increasing the potential of exchanges between energy networks, enhancing security of supply, creating business opportunities, avoidance of curtailment and offering new services to the grid.
- Consideration of human behaviour in the design of infrastructure and demand response to avoid blockages due to social acceptance, placing the consumer at the centre of the energy system.

### INTERPLAN Consortium

### DERlab network in INTERPLAN

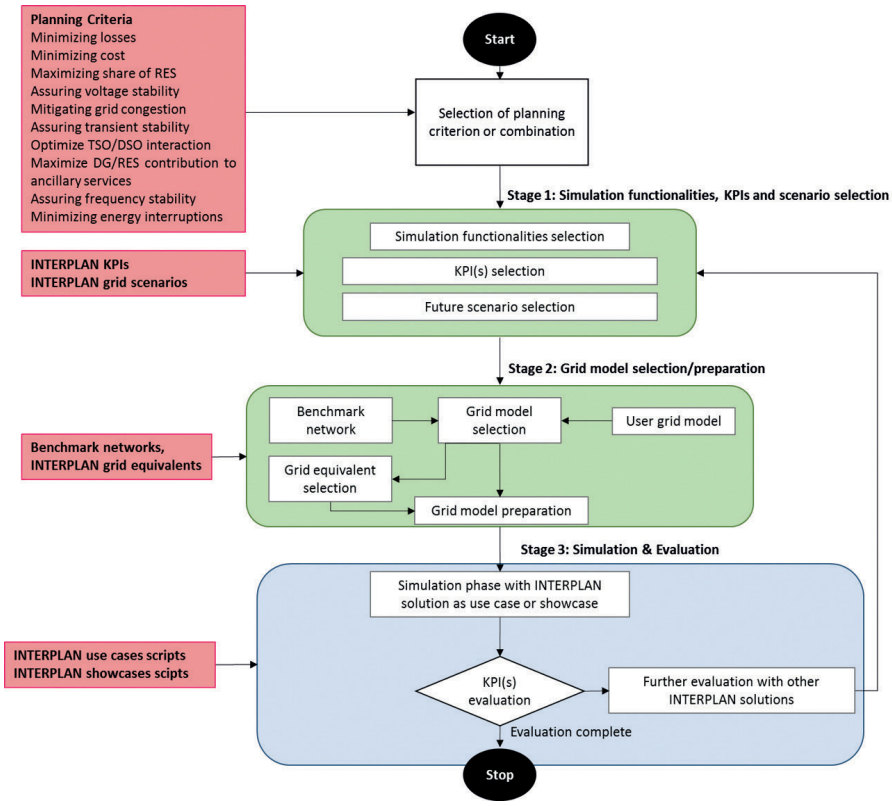
INTERPLAN partners AIT, FOSS and Fraunhofer IEE are members of the DERlab association. They are fully involved in the development of the grid operation planning tool as well as grid clustering and equivalenting methodologies. Moreover, the whole network of DERlab members are regularly consulted through workshops, consultation forms, etc. about project alignments and activities. This brings a great opportunity for the project consortium to gain valuable feedback which is based on expertise and several years of experience of DERlab members in developing and validating smart grids systems and technologies.

# The INTERPLAN Operation Planning Tool

**The INTERPLAN methodology provides a set of tools (grid equivalents, control functions) for the operation planning of the pan-European network. The tool addresses a significant number of system operation planning challenges of the current and the future 2030+ EU power grid and it does this from both the perspective of the transmission system and the distribution system, with a particular focus on the transmission-distribution interface.**

In this sense, the main goal of the tool is to achieve the operation planning of an integrated grid from the perspective of a TSO or a DSO, through handling efficiently and effectively intermittent RES as well as the emerging technologies such as storage, demand response and electric vehicles. In fact, the tool supports utilising flexibility potential coming from RES, Demand Side Management, storage and electric mobility for system services in all network control levels.

The flowchart representing the INTERPLAN tool overview, including the various stages that the user (TSO or DSO) can perform for the operation planning of the network under consideration, is shown in the figure below.




**INTERPLAN tool overview**
As shown in the figure, the user, identified as a TSO or a DSO, selects the planning criteria he wants to consider for the network operation planning. This selection is based on the list of planning criteria identified in the project.

After the planning criteria selection, the following three stages are performed by the user:

**Stage 1:** Simulation functionalities, Key Performance Indicators (KPIs) and scenario selection
**Stage 2:** Grid model selection/ preparation
**Stage 3:** Simulation & Evaluation

Assuming that the user knows from the beginning the operational challenge that requires investigation, the tool will guide them towards the most suitable INTERPLAN solution (use case and showcase-related control functions). Indeed, the three stages have been structured to guide the user selecting the most proper INTERPLAN solution in function of the operation challenge the user wants to investigate in a specific network as part of the distribution system, the transmission system or the transmission-distribution system. According to this approach, all the possible selections enabled will be known to the user in advance through the INTERPLAN user manual.

**From the practical point of view:**
The INTERPLAN tool will be a Python-based toolbox interfacing with PowerFactory (under the simulation phase in stage 3), consisting of a library of grid equivalents and control functions for use cases and showcases for addressing the related operational challenges under the selected scenario and operation planning criteria.

**Reference person: Dr. Marialaura Di Somma (ENEA)**
**Contact: marialaura.disomma@enea.it**

# INTERPLAN Use cases and Showcases

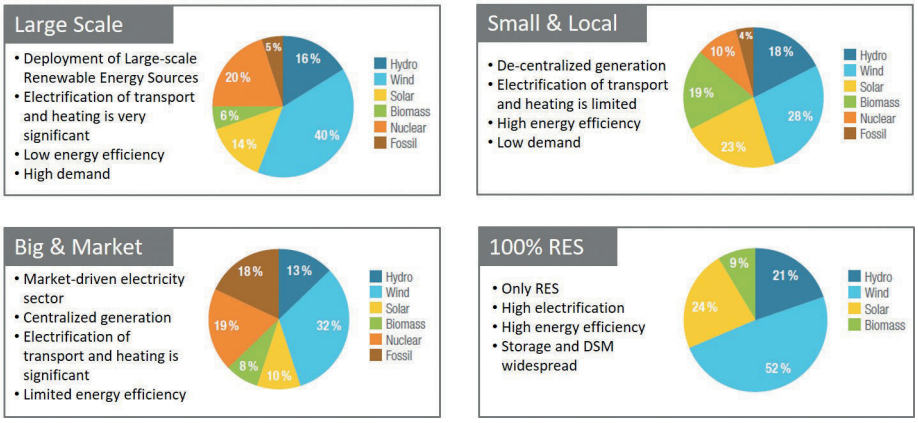
The INTERPLAN use cases go beyond the current regulations and grid codes, proposing solutions to address the challenges a high concentration of new technologies such as RES, storage and demand response pose for the future operational planning of the EU grid. As it stands, current grid codes and practices are inadequate to fully address these challenges.

INTERPLAN has developed seven use cases:

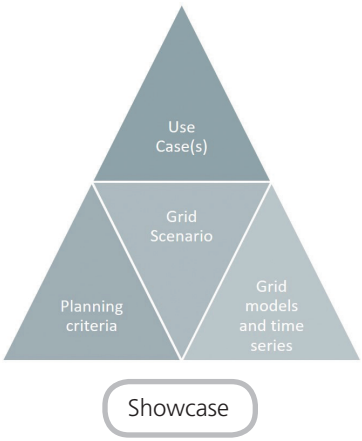
**UC1: Coordinated voltage/reactive power control**
**UC2: Grid congestion management**
**UC3: Frequency tertiary control based on optimal power flow calculations**
**UC4: Fast Frequency Restoration Control**
**UC5: Power balancing at DSO level**
**UC6: Inertia management**
**UC7: Optimal generation scheduling and sizing of DER for energy interruption management**

**In INTERPLAN, a use case is defined as "the specification of a set of actions performed by a system, which yields an observable result that is typically of value for one or more actors or other stakeholders of the system" (source: IEC 62559).**

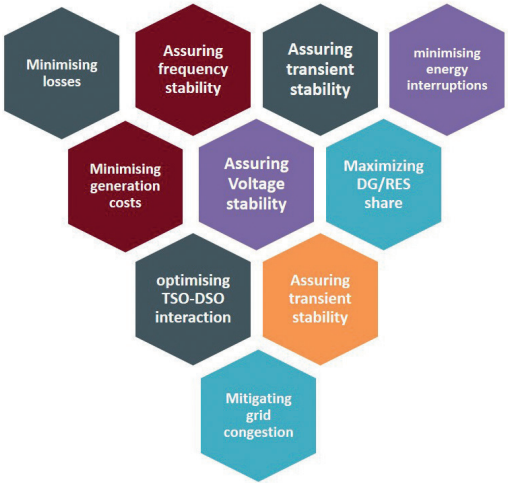
In the case where proposed solutions are positively evaluated in simulation scenarios for later stages of the project, they will be used to inform and recommend amendments to existing grid codes and European regulations.




Future European Grid Scenarios © e-Highway 2050 Project




**INTERPLAN defined showcases in order to prove the applicability of the tool, by considering the identified grid scenarios and use cases presented above. A showcase comprises a presentation of a use case(s) in the frame of a chosen scenario, simulation type, test grid model, time-series data and planning criteria. Showcases normally include scope, description, beneficiaries, Grid model, sub-use cases and a sequence diagram.**




In total, five showcases were defined for the operation planning tool. Additionally, for each showcase, a base showcase was created – with no planning criteria and no controllers for emerging technologies – in order to analyse the operational challenges of the related use cases, and demonstrate the improvements that could be achieved through the application of revised planning criteria and operational controls.

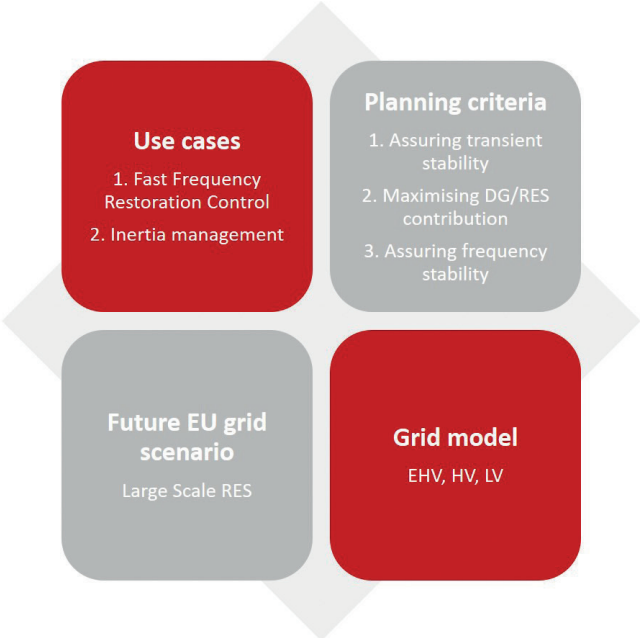
**Reference person: Ata Khavari (DERlab)**
**Contact: ata.khavari@der-lab.net**

## Showcase: Frequency control for low inertia systems

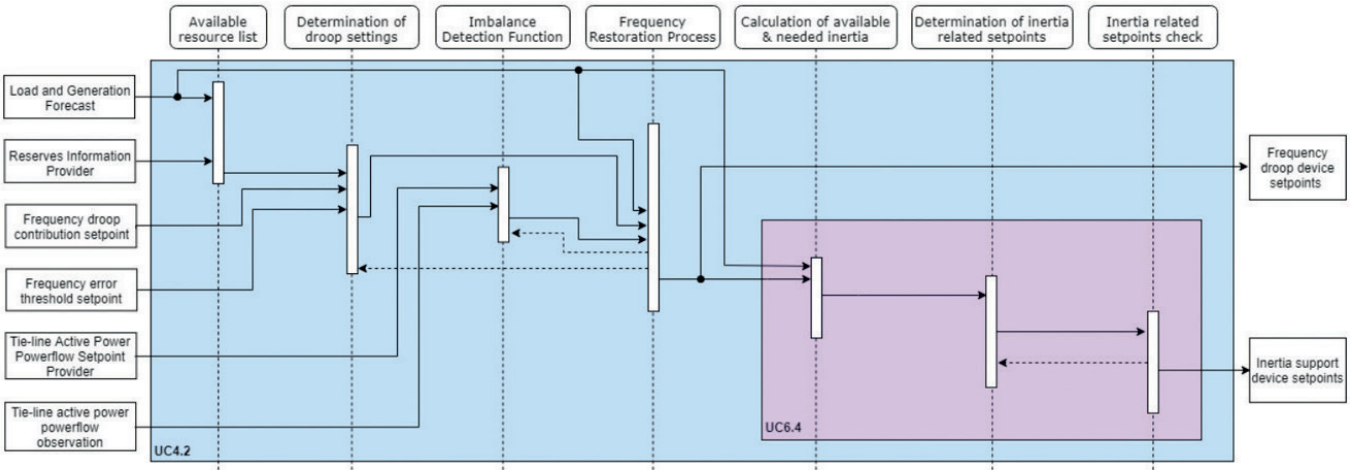
Power systems with low concentration of synchronous generation, and consequently low total system inertia, are vulnerable to power imbalances. Such systems can experience frequency stability problems, such as high frequency excursions and higher rates of change of frequency. Therefore, the main focus of this showcase is to demonstrate how frequency stability in low inertia systems can be assured through the capabilities of additional technologies such as RES, DG, controllable loads and storage systems.

### The process

This showcase combines inertia management with fast frequency restoration control. Frequency stability of the first swing in the proposed solution is managed by estimating available and required inertia for given system conditions, and then utilising the required inertia through synthetic inertia and fast frequency response controllers. For further reinforcements, Optimal Power Flow-based frequency restoration is added, which, by using available energy sources, brings the frequency to its nominal value.




Graphical representation of parameters involved in the showcase




Sequence diagram for this showcase

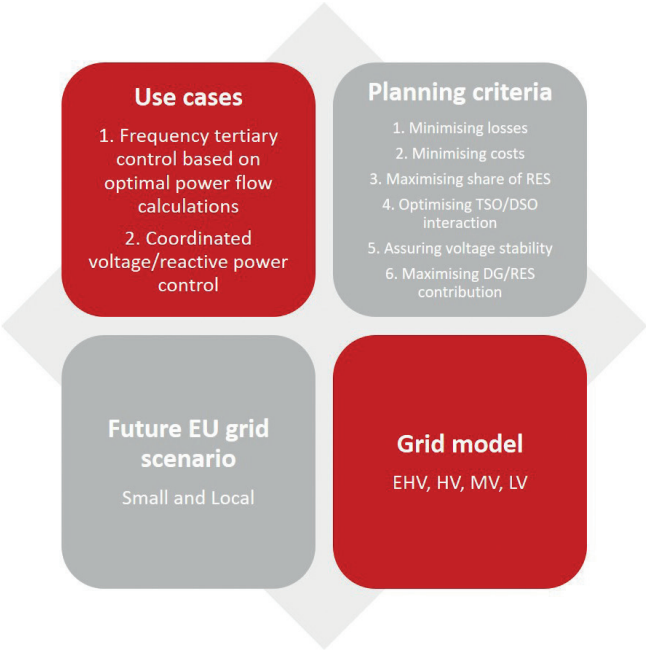
## Showcase: TSO-DSO coordinated active and reactive power flow optimisation at all voltage levels

The main focus of this showcase is to present an optimisation strategy for the parallel control of active and reactive power across the transmission and distribution grids. The optimisation strategy will maintain voltage quality at both network levels, as well as support participation in the tertiary reserve market and facilitate the TSO's management of network stability. The control strategy must ensure an optimisation of both active and reactive power of all available resources, with no conflict in setpoints, considering the constraints.

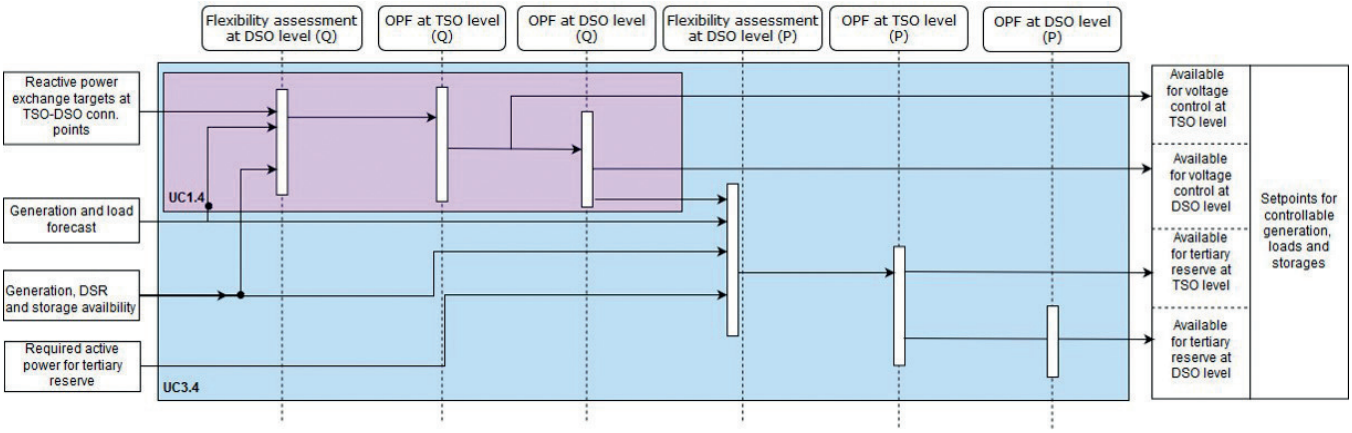
### The process

First, available flexibility in the distribution grid is assessed based on required reactive power for voltage control as well as forecasted load and generation. Using this information, an Optimal Power Flow for the transmission grid is performed, giving reactive power setpoints for generation, loads and storages, connected to the transmission grid.

In the next step, an OPF at the distribution level is calculated. Setpoints obtained from this OPF are sent to the relevant power objects, which are available for reactive power control. Then, all the setpoints will serve as constraints for active power flow optimisation at both transmission and distribution levels, which aims to provide required active power for frequency tertiary control. This optimisation is performed with the similar sequence of actions as with the reactive power optimisation. The final setpoints are sent to the resources, which are available for tertiary reserve.




Graphical representation of parameters involved in the showcase




Sequence diagram for this showcase

# Grid clustering and equivalenting

Clustering is an effective machine learning technique being used in data exploration, based on the grouping of feeders or networks into clusters of specific features. The computational complexity of grid clustering is linearly proportional to the size of the data set. The main advantage of clustering is a significant reduction of computational complexity by clustering the similar data types.

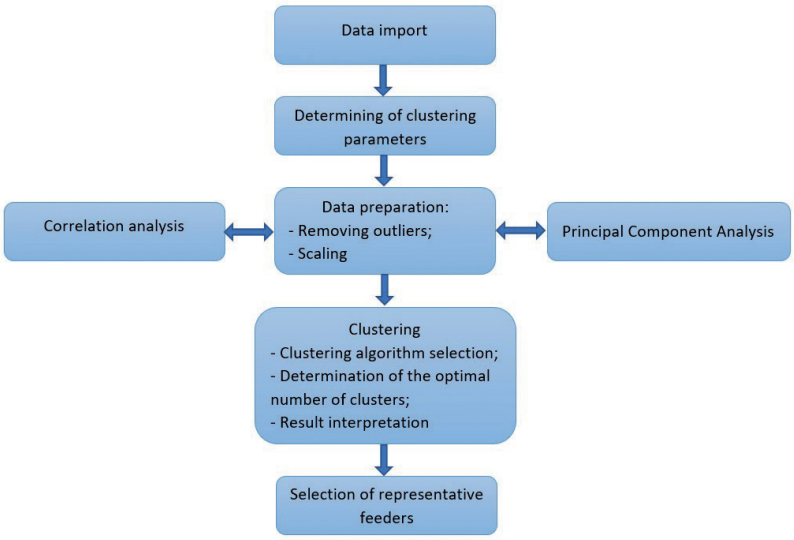
As the number of feeders connected to low voltage grid is quite high, the assessment of these feeders for future loading and the required alterations in the feeders individually is tedious and time-consuming. Clustering implies grouping of observations into clusters, based on the similarity of their specific parameters. The clustering of feeders to set a generic type, which can be studied in detail, can provide a suitable alternative.

**INTERPLAN is operated with a database for 2000 low voltage networks, comprising approximately 9500 low voltage feeders. The grid clustering methodology is used to decrease the associated computational complexity. INTERPLAN considered transmission and distribution grid models in grid clustering, based on the impact they might have on different feeder types and distributed generation hosting capacity.**

## The methodology in summary

The process starts with importing network data and processing them with a software, in this case DIgSILENT PowerFactory, and then scripting with Python software, which allows a high computational functionality and flexibility for data exchange. Data importation is used for determining the cluster parameters.

Various analyses like statistical, principal component and clustering analysis are applied and the clusters produced by grouping are graphically depicted. These analyses help in data preparation, removal of outliers and scaling.




Grid clustering covers different use cases for semi-dynamic and integrated grid operation planning involved in INTERPLAN. It considers a wide range of grid parameters and regressors (e.g. average installed RES per point of connection) as the clustering criteria is given by different Key Performance Indicators (KPIs) associated with each sub-case.

Clustering involves algorithm selection, determination of optimal number of clusters and result interpretation. In order to generate grid clustering models, various grid models in different scenarios are considered in INTERPLAN and suitable grid clustering parameters are chosen for feeder clustering.

In the last step of the clustering approach, a set of representative feeders are identified. When a new feeder is given, analysing and identifying the characteristics of such feeder is similar to a classification step, by assigning it to one of the already identified classes of feeders. A descriptive value for the KPI associated with these particular feeders can then be directly obtained from the representative feeders for further analysis.

**Reference person: Dr. Mihai Calin (AIT)**
**Contact: mihai.calin@ait.ac.at**

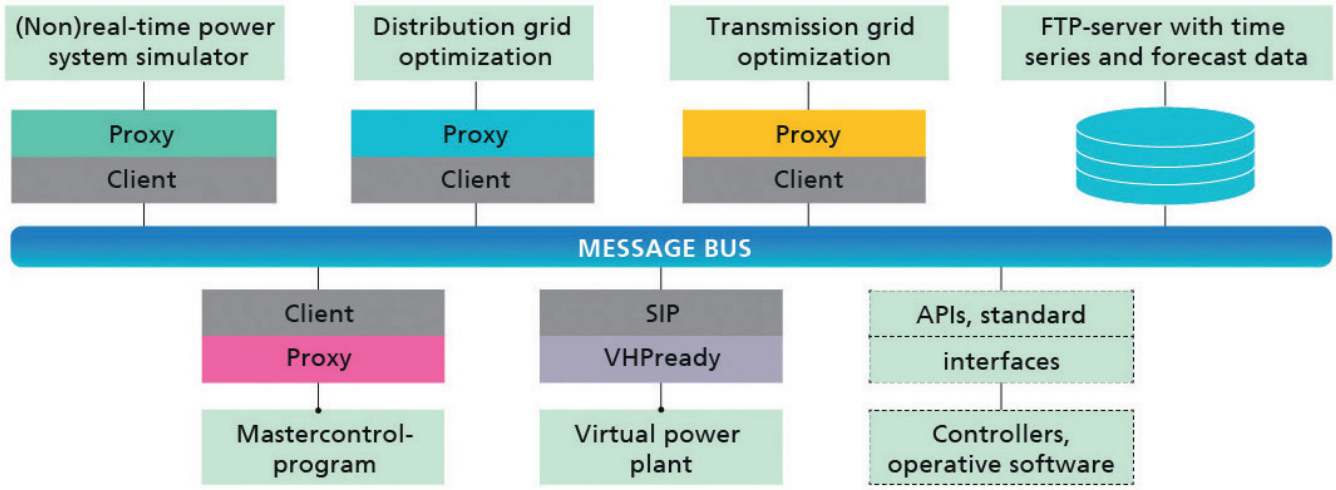
# OpSim: a co-simulation tool for INTERPLAN

OpSim is a co-simulation and test platform which was initially developed by Fraunhofer IEE and University of Kassel in the German research projects OpSim and OpSimEval. It is intended for simulation of operation and control strategies and aggregators in smart grids with a very high share of renewable generation. The simulation environment includes virtual power plants, distribution and transmission system control strategies and energy management systems of distributed generators, storages and loads. Using the environment, co-simulations can be both executed in real time and accelerated.

The OpSim environment is a unique facility for the development of grid control strategies and their testing in realistic conditions. Of particular note is the ability to analyse and optimise multiple interacting control strategies. OpSim applications are ranging from developing prototype controllers to testing operative control software in the smart grid domain. OpSim is maintained by Fraunhofer IEE and University of Kassel and enables users to connect their software to simulated power systems, or test it in conjunction with other softwares. The power grid simulator of OpSim is capable of emulating large power systems with multiple voltage levels and substantial amounts of generators, storages and loads.

Control strategies can be global, distributed or agent-based. In addition, OpSim focuses on the interaction between two or more control strategies, e.g. a setpoint agreement scheme between DSO and TSO, and their effect on the power grid.

**OpSim supports standardised interfaces including Websockets, REST, IEC 61850, IEC 60870-5-104, CIM, and VHPready. As extension of OpSim, a webservice component is available enabling remote simulation subcomponents that access the co-simulation over REST or WebSocket technology. This functionality is called "OpSim as a service" and is planned to be used in INTERPLAN for enabling co-simulation subcomponents representing controllers running at project partners, while the physical grid simulation runs at the OpSim server hosted by IEE.**




**http://www.opsim.net/en**

**Reference person: Dr. Jan Ringelstein (Fraunhofer IEE)**
**Contact: jan.ringelstein@iee.fraunhofer.de**

**Giorgio Graditi**

*Coordinator of the INTERPLAN project, Vice Director of Energy Technologies Department, ENEA*

**Giorgio Graditi**. He received the doctoral degree and the Laurea degree (cum laude) in electrical engineering from the University of Palermo (Italy). Since 2000, he has been a Researcher at ENEA, Italian National agency for new technologies, energy and sustainable economic development. From October 2011 until August 2018, he was the head of Photovoltaic Systems and Smart Grid Unit of ENEA; since September 2018, he has been leading the Solar Thermal and Smart Network Division of ENEA, and since June 2019, he has been the Vice Director of Energy Technologies Department of ENEA. He is actually serving as Coordinator of the Scientific Technical Committee of Italian Technological Cluster on Energy and he is also the president of MEDENER.

In 2017, Giorgio Graditi received the Italian National Scientific Qualification as Full Professor in the sector of electrical energy engineering. His main research interests are in power systems design and control; power system conversion; PV, CSP electrical and thermal design, characterisation and testing; microgrids and smart grids modelling and analysis; design, management and control of multi-energy hub systems by multi-objective optimisation approach.

Giorgio Graditi is responsible for national and European (FP7, H2020) projects within renewable energy and smart grid topics. He is the vice-coordinator of Joint Programme on Smart Grid (JP SG) within European Energy Research Alliance (EERA). He is operating as Italian member for Mission Innovation Challenge 1 "Smart Grids" and Challenge 2 "Off-grid access to electricity", and as a member of the national board of directors of H2020 for "Secure, Clean and Efficient Energy".

## Interview with Giorgio Graditi

**What is the main contribution of INTERPLAN to the power system operation and who are the main stakeholders?**

The European Union energy security policy faces significant challenges as we move towards a pan-European network based on the wide diversity of energy systems among EU members. In such a context, novel solutions are needed to support grid operators for the future operation, resilience and reliability of the EU electricity system in order to increase the security of supply by also accounting for the increasing share of renewable energy sources (RES). INTERPLAN tool will support TSOs and DSOs in the operation planning of the pan-European network, while also fostering the achievement of the low-carbon objectives targeted by the European Commission for 2030 and 2050. **In this sense, the main stakeholders for the project are the TSOs and DSOs. This is because the main objective of the tool is to achieve operation planning of an integrated grid from the perspective of the grid operators. This is done via efficient and effective handling of the intermittent RES as well as utilising emerging technologies such as storage, demand response and EVs.**

The project will also provide a methodology for a proper representation of a "clustered" model of the pan-European network. The purpose of this is to form a working library of generated grid equivalents that cover a range of relevant system connectivity possibilities found in real grids. This is done by addressing a number of operation planning issues at every network level, from distribution to transmission and the TSO-DSO interface.

**The INTERPLAN consortium has been interacting and consulting with experts from system operators and similar projects. How can this affect the developments in the project?**

Since the beginning, the involvement of external stakeholders in the project's activities has represented a crucial aspect for the INTERPLAN consortium. Indeed, informing and involving additional stakeholders such as grid operators, public authorities, industry representatives, energy utilities and research organisations other than those already involved in INTERPLAN, with the aim to increase the project impact, enables the fostering of a culture of cooperation between research infrastructure providers, grid operators and scientific communities. Moreover, it increases the visibility and impact of the project and allows for valuable feedback about the project developments and results.

**In accordance with this objective, INTERPLAN established the novel approach of actively involving external stakeholders since the beginning of the project through organising a series of targeted workshops as well as surveys for validating and complementing the intermediary results achieved. So far, three workshops have been organised and about 90 stakeholders are involved in the project.**

Getting in touch with the relevant stakeholders to receive feedback and recommendations, especially about the use cases, the showcases and the tool itself, is of major importance for the project.

**Why is INTERPLAN looking at the potential operation challenges specifically in the future pan-European grid?**

INTERPLAN looks into the potential operation challenges which TSOs and DSOs are called to address in the 2030+ power system. In fact, the ongoing deployment of the pan-European Network strongly depends on different potential scenarios related to the RES share in generation and installed capacity, as well as the penetration of emerging technologies, such as storage and Demand Response (DR). Although these factors represent the preferential patterns to meet the EU decarbonised energy targets for 2030 and 2050, they bring new challenges for the energy system, which will outline the key operational needs of the European grid operators in the near future.

In such a context, TSOs will need to evolve progressively from a "business as usual approach" to a proactive approach in order to avoid a bottleneck effect in the future European grid - this could be addressed through a proper system operation planning. As for the distribution networks, they have been traditionally designed and treated to transport electrical energy in one direction, i.e., from the generation units connected to the transmission system to the end-users. However, with the growing share of non-dispatchable distributed generation, customers are increasingly generating electricity themselves, and, by becoming "prosumers", they are shifting from the end point to the centre of the power system. As a result, DSOs will need to actively manage and operate a smarter grid through appropriate system control logics, by utilising the flexibility potential in the grid, with the aim to optimise the distribution network performance.

Furthermore, an additional critical issue is the interface between transmission and distribution systems which is expected to evolve in the near future, through a mutual cooperation between TSOs and DSOs. The aim is to address operational challenges such as congestion of transmission and distribution lines and the interface between them, voltage support between TSOs and DSOs as well as power balancing concerns. The increasing complexity of the grids requires control and operation planning tools even more advanced and homogenous among European countries. **With these premises, the INTERPLAN idea was born. The project aims to develop control system logics which suit the complexity of the integrated grid, while managing all relevant flexibility resources as "local active elements" in the best manner. Moreover, by looking at the 2030+ power system, the project also addresses policy and regulation aspects, aiming to identify a set of possible amendments to the existing grid codes, reflecting the developments achieved in INTERPLAN through its tool, use cases and showcases. The aim of this analysis is to break down the current barriers to the integration of emerging technologies and to foster TSO-DSO cooperation in managing grid operation challenges.**

Stakeholder workshop at SEST 2019 in Porto (PT) 2019

INTERPLAN Consortium at European Utility Week 2018

**Will INTERPLAN open source their tools? And how to access those tools?**

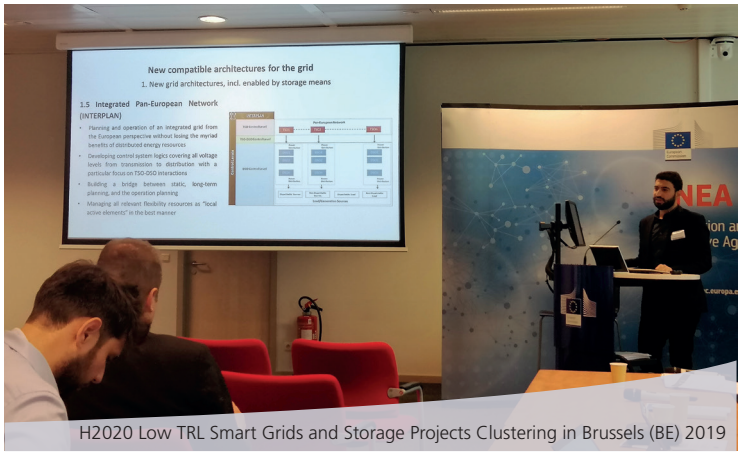
The developed network planning and operation tools are based on established commercially available products, like Python and PowerFactory, that are widely used by the industry, aiming to be readily available for immediate adoption and implementation. The INTERPLAN consortium is making a common effort to create open source tools and models, with the aim to offer the possibility for researchers from academia, industry as well as grid operators to further develop, validate and integrate these tools.

In practice, a detailed user manual for the INTERPLAN tool will be made available for open and wide use by all interested stakeholders and / or software developers. Additionally, the consortium intends to provide an integrated tool to the prospective users with the following features and advantages:

- It will include an exhaustive library of grid equivalents in CIM-Format responding to all known needs of operators and system analysts and covering all voltage levels and their active components.
- It will provide easy-to-use grid clustering techniques that are adaptive and responsive to the dynamic growth of the evolving grid, thus refining and validating the use of new technologies as they emerge and are integrated within grids.
- The integrated clustering algorithms can, due to their open source character, be applied to other grid areas and voltage levels. Hence, it can be the basis for further development.
- The integrated control system logics can be applied to other grid areas and different voltage levels, thereby representing a source for further development and integration.

In conclusion, the consortium will ensure to make the achievements of the project available for further research, in order to widen the scope and functionality of the developed tools. To make a practical example, in developing the integrated network operation planning tool, the consortium identified the need for further research and advancement in order to cover aspects such as ICT, cyber-security, and user friendly GUI (graphical user interface) of the tool.

4th Mission Innovation – IC1 deep-dive workshop in Rome (IT) 2018



H2020 Low TRL Smart Grids and Storage Projects Clustering in Brussels (BE) 2019

**Helfried Brunner**

*Technical Coordinator of INTERPLAN project, Senior Research Engineer and Thematic Coordinator power system planning and operation, AIT (Austrian Institute of Technology)*

**Helfried Brunner.** He is with AIT - Austrian Institute of Technology as Senior Research Engineer and Thematic Coordinator for power system planning and operation, and responsible for related projects and the competence portfolio in this topic. He is Austrian Alternate ExCo member within the IEA International Smart Grid Action Network (ISGAN). Helfried is a member of the board of the National Technology Platform Smart Grids Austria and member of the CIRED Technical Committee as Session 4 rapporteur. Helfried is AIT representative within the European Energy Research Alliance (EERA) Joint Program on Smart Grids, and from 2013 to 2018 he was Technical Coordinator of the EERA Integrated Research Program ELECTRA. From 2011 until 2018, he was lecturer in the field of electricity networks at the University of Technology Vienna and University of applied sciences Technikum Wien.

## Interview with Helfried Brunner

**What are the main exploitable results of INTERPLAN and what is your plan to ensure the sustainability of the project outcomes?**

The most exploitable result is the integrated planning toolset itself and the experiences we gained by integrating the different use cases. The toolset is a prototype, in order to show the feasibility as well as the value of an integrated grid planning, covering different voltage levels as well as different time scales.

The most important factor to ensure the sustainability of the project outcomes is to be in continuous contact with grid stakeholders, in particular with system operators, in order to meet their actual future demand. This is done via individual contacts as well as dedicated workshops. To move towards commercialisation of the integrated planning tool, the consortium is going to approach simulation software vendors in the later project phase.

**What are, according to you, the main barriers from the regulatory and technical point of view for implementing a real cooperation between TSOs and DSOs to solve operation challenges of the integrated grid?**

The main regulatory barrier to the cooperation between TSOs and DSOs is the unbundling of them. In order to implement real cooperation, it is needed to agree upon what information, at which aggregation level needs to be exchanged between the two entities. This requires a clear picture about the future use cases and the interaction required by them. From a purely technical perspective, the main issue is to provide harmonised communication and information interfaces between DSOs and TSOs. Additionally, the exchanged information needs to be integrated in the individual planning and operation tools or in an integrated planning tool, like the one INTERPLAN is designing.

**From INTERPLAN perspective, how can the energy community boost the interaction between TSO-DSO?**

The energy community enables INTERPLAN to gain more information about the actual status of the energy consumption, as well as the flexibility provision for different applications at energy community and distribution grid level. By aggregating the available flexibility and related information at DSO level, it is easier to provide related services to the TSO without causing distribution system congestions.

**How could other actors in the energy field, apart from the TSO and DSO, benefit from the tool developed within the project?**

An integrated grid operation planning tool will provide support for increased flexibility, giving energy system actors, including the end users, the ability to deliver new services. The analysis within the tool allows the development and operation of the interconnected grid of tomorrow through seamless integration of renewable energy resources and related technologies, such as storage and aggregated flexibilities. In addition, a detailed assessment of the regulatory framework in Europe, including existing grid codes, is possible. This will support all grid stakeholders, including regulatory bodies, in their decision-making processes.

**Can you share with us any practical experience on grid clustering and equivalenting for which a new methodology will be developed in INTERPLAN?**

To allow integrated grid planning across different voltage levels, grid data is required to be shared, together with capacity limits, and a number of increasingly complex data sets. A TSO will not be able to incorporate complete data sets from downstream DSOs, nor will a DSO be able to implement complete data sets of a neighbouring DSO or upstream TSOs. This is why, in order to limit complexity, grid equivalent models need to be provided and generated, to represent the behaviour of the real neighbouring, up or downstream networks.

# DERlab Research Infrastructure Testing and Consulting Services

| | High Voltage & High Power | Microgrids & Distribution Network | Power Electronics | Power Quality & EMC | PV Systems | Wind Systems | Biomass / CHP Systems | Fuel Cell Systems | Storage Systems | E-Mobility | Smart Buildings | ICT | Cybersecurity | HIL / Co-simulation | Education & Training |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 Austrian Institute of Technology (AT) | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 2 & 3 VITO & EnergyVille (BE) | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | | | ■ | ■ |
| 4 Lemcko of Ghent University (BE) | | ■ | | ■ | ■ | ■ | | | ■ | ■ | ■ | | | | ■ |
| 5 Technical University of Sofia R&DS (BG) | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 6 HES-SO Valais (CH) | | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 7 FOSS of the University of Cyprus (CY) | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | | | ■ | ■ |
| 8 Brno University of Technology (CZ) | ■ | | ■ | ■ | | | | | | | | | | | |
| 9 Fraunhofer IEE (DE) | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | | | ■ | ■ |
| 10 Karlsruhe Institute of Technology (DE) | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 11 RWTH Aachen (DE) | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 12 DTU Electrical Engineering (DK) | ■ | ■ | ■ | | ■ | ■ | | | ■ | ■ | ■ | ■ | | ■ | ■ |
| 13 CRES (EL) | | ■ | ■ | ■ | ■ | | | | ■ | | ■ | ■ | | | ■ |
| 14 NTUA (EL) | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 15 CIEMAT (ES) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | | ■ | | | | |
| 16 EES-US Group of the University of Seville (ES) | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | | | ■ | ■ |
| 17 SEER (ES) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | |
| 18 TECNALIA (ES) | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 19 VTT Technical Research Centre of Finland (FI) | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 20 TUAS (FI) | | ■ | ■ | ■ | ■ | | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 21 University of Vaasa (FI) | ■ | ■ | ■ | ■ | | | | | ■ | | ■ | ■ | ■ | ■ | ■ |
| 22 CEA-INES (FR) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | | | | |
| 23 EDF (FR) | | ■ | ■ | | ■ | | | | ■ | ■ | ■ | ■ | ■ | ■ | |
| 24 Enel (IT) | | | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | | | |
| 25 RSE (IT) | ■ | ■ | ■ | ■ | ■ | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | |
| 26 SnT (LU) | | ■ | | | ■ | | | | ■ | | ■ | | | ■ | |
| 27 DNV GL (NL) | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 28 TNO (NL) | | ■ | | | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 29 TU Lodz (PL) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | ■ | ■ |
| 30 INESC Porto (PT) | | ■ | ■ | ■ | ■ | ■ | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 31 MicroDERlab Group (RO) | | ■ | ■ | ■ | ■ | | | ■ | ■ | | ■ | ■ | ■ | ■ | ■ |
| 32 University College Dublin (IE) | | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | | | ■ |
| 33 University of Manchester (UK) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 34 University of Strathclyde (UK) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 35 NREL (US) | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ | ■ |
| 36 Sandia DETL (US) | | ■ | ■ | ■ | ■ | ■ | | ■ | ■ | ■ | ■ | ■ | ■ | ■ | |

The transition towards high shares of renewable energy and more decentralised energy supply requires a smarter grid with sufficient hosting capacity and the ability to manage the significant power fluctuations of renewable sources. High-level research and laboratory tests are vital to tackling these challenges. With the necessary expertise and capabilities, laboratories of DERlab members provide the services of testing individual components and complete systems, and verifying compliance with international and national standards or certification procedures.

# AIT Strengthening Real-Time Simulation Capabilities

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

AIT AUSTRIAN INSTITUTE OF TECHNOLOGY

The **Austrian Institute of Technology (AIT)** is Austria's largest research and technology organisation. The main research areas of AIT are energy, mobility systems, low-emission transport, health and bio resources, digital safety and security, vision, automation and control, and technology experience, all paired with competence in the area of innovation systems and policy.

**infrastructure.der-lab.net/ait**

AIT disposes of a vast variety of testbeds, which facilitate power system evaluation and include ICT/automation tools and components, simulation tools and components, and electrical setups and components. A HIL setup lets researchers integrate real power system components into a virtual grid environment and test them as they interact with the grid under realistic conditions.

AIT SmartEST lab also includes a Data Analytics Lab with a 24 node / 48 CPU / 288 core parallel cluster infrastructure, including 3TB RAM and 100TB distributed storage systems. The scalable network filesystem is based on GlusterFS, a large distributed storage solution for data analytics and other bandwidth intensive tasks. Research on procedures for advanced interoperability testing of single, as well as multiple, DER units under different grid control schemes supports the integration of DERs into a future smart grid through standardised communication and coordination among generators, consumers, and storage units.

AIT also extended its real-time simulation capabilities. Now, three different types of Digital Real-Time Simulators (DRTS) – OPAL-RT, Typhoon HIL, and PLECS RT Box – are available for performing simulation and HIL-based studies on power networks and power electronics.

## New capabilities in 2020

Until the end of 2020, AIT will be extending its testing capabilities in the field of DC high current and energy storage systems (ESS). The existing laboratory used for high current and short-circuit testing of AC equipment will be complemented with a dedicated facility for high current DC testing. The facility will allow short circuit testing of DC switchgear and DC assemblies for LV and MV applications with peak currents up to 150 kA at voltages up to 4 kV. The new ESS test facility will provide a fail-safe environment for extended qualification, performance and lifetime tests of battery assemblies and complete systems for residential as well as commercial applications. Both facilities will be directly linked to the existing AIT SmartEST laboratory infrastructure and complement its testing range for power electronic converters and smart grid equipment.

## Consulting services

AIT provides research and development support to a broad portfolio of customers including network operators, energy service providers, manufacturers, and public bodies. AIT's service portfolio includes technical studies, economic assessments, technology development support, prototyping and lab testing.

AIT's SmartEST Laboratory

AIT's SmartEST Laboratory

## Research activities

AIT, together with TU Vienna, Verbund and the Austrian TSO APG, are working towards the definition of novel ancillary services and products to address new issues arising due to the massive penetration of renewable sources. New functionality has been proposed in the context of the ABS4TSO (Advanced Balancing Services for Transmission System Operators) project. These new functions have been implemented in a 1MW/500kWh storage unit that is being deployed at an APG substation.

AIT has developed an automatic HIL testing procedure that validates novel functionality aiming at frequency stability issues arising nowadays in low inertia grids. The existing HIL setup is verified against the expected response (modelled in a pure simulation environment) and validated against laboratory tests. Such a setup allows to properly define the specification of novel ancillary services based on the real behaviour of non-synchronous sources.

The Integration of Loads and Electric Storage Systems into advanced Flexibility Schemes for LV Networks (leaves) project led by AIT evaluated the effects of increased consumer and energy market-driven utilisation of energy storage systems (ESS) and load flexibility on low voltage (LV) power distribution grids. New technologies and operation strategies were developed which enable the optimal use of distribution grid infrastructure through the activation of available flexibilities using direct or indirect control schemes operated by the local distribution system operator (DSO) or via the implementation of monetary-based customer incentives. Flexibility, in the context of this project, is defined as the active alteration of the system power level and/or a shift in time. Network planning approaches might have to change since new technologies such as distributed ESS and EVs can be operated flexibly.

Moreover, existing components such as heat pumps and domestic hot water boilers can be operated in such a flexible way. Before the rollout in the field, complete system tests were performed in the AIT SmartEST laboratory for the developed components and operation strategies. During these tests, the complete ICT system was recreated incorporating all relevant components that are also installed in the field test. The tests focused on both the residential PV-BESS and central BESS set up in the field trials.

## Partnerships

AIT holds the position of Operating Agent for the International Energy Agency (IEA) Technology Collaboration Programme (TCP) for a co-operative Programme on Smart Grids (ISGAN – International Smart Grids Action Network). Furthermore, AIT continues to be active in several international networks: European Energy Research Alliance (EERA), Institute of Electrical and Electronics Engineers (IEEE), European Technology and Innovation Platform's SNET and PV, European Center for Power Electronics (ECPE), International Electrotechnical Commission (IEC), Congrès International des Réseaux Electriques de Distribution (CIRED), and Conseil International des Grands Réseaux Électriques (CIGRE).

# Co-Simulation and New Resilience Testbed at NREL

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Grid / Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

NREL
Transforming ENERGY

The **National Renewable Energy Laboratory (NREL)** is the US Department of Energy's (DOE's) primary national laboratory for renewable energy and energy efficiency research. From scientific discovery to accelerating market adoption, NREL deploys its deep technical expertise and unmatched breadth of capabilities to drive the transformation of the nation's energy resources and systems.

**infrastructure.der-lab.net/nrel**

In 2019 NREL completed and incorporated the co-simulation platform HELICS, the Hierarchical Engine for Large-Scale Infrastructure Co-Simulation. HELICS interfaces between energy domains and their respective modelling tools to perform grid simulation and analyses, allowing cyber-physical demonstrations of interdependent, large-scale energy systems.

NREL also finalised its advanced distribution management system testbed. The testbed allows users to validate grid management applications, and pilot and plan control scenarios within a real distribution system environment. Three use cases helped validate the new testbed, spanning topics in DER optimisation and data management.

## New capabilities in 2020

NREL will continue to build out its security and resilience testbed, which will consolidate and refine tools to plan around future vulnerabilities associated with smart grid technologies. The security and resilience testbed integrates with other grid simulation tools at NREL, including a suite of real DER hardware and advanced management platforms.

NREL's cross-campus ESI testing environment will be ready for use in large-scale grid demonstration activities in 2020. The environment includes many megawatts of wind power, battery energy storage, solar arrays, as well as a controllable grid interface. This environment will help understand grid control at real power, as well as how innovative power technologies will interoperate.

NREL researchers in the Energy Systems Integration Facility. Photo by Dennis Schroeder, NREL

## Strategic partnerships

The Energy Systems Integration Facility at NREL is a user facility, granting collaborators access to state-of-the-art equipment and domain experts.

Services are also offered in the context of site-specific evaluations for cybersecurity and technical reviews, component testing, panel positions, and all work pertaining to partnerships with both large and small organisations. For more information, visit **nrel.gov/esif**.

## Accomplishments

In 2018-2019, energy systems integration research at NREL delivered dozens of patents and records of invention.

NREL's smart home management software **foresee** won an R&D 100 award, and NREL's new high-performance computing center was awarded the Data Center Eco-Sustainability Award from Data Center Dynamics.

## Research activities

NREL has collaborated extensively with utilities in the United States to improve their grid operation. In Hawaii, NREL is developing software for grid state estimation, a technique for controlling DER behaviour with limited measurements. It is being studied in a laboratory setting near by the Hawaiian utilities. The software will empower Hawaii to effectively control its record level of residential solar instalments.

In a similar partnership, NREL and the Sacramento Municipal Utility District (SMUD) created PRECISE, a software for automated programming of inverter settings. PRECISE saved SMUD from an overwhelming number of residential solar instalment applications by streamlining the review process. PRECISE went into use in 2019 and will also reduce the number of costly infrastructure upgrades that SMUD and other utilities face.

In general, NREL's grid planning and operation research spans are relevant subtopics. Strides in grid and weather forecasting will improve real-time operations, while technical breakthroughs in optimisation and machine intelligence-based mechanisms for grid control are finding first application in grid management systems, including a new affordable housing development in rural cooperative Holy Cross Energy's jurisdiction. NREL also finalised SMART-DS, which generates "realistic but not real" power system datasets to overcome limited access to proprietary datasets.

## Partnerships

A close partnership with Eaton is driving innovation across smart grid technologies, most notably in mobility, where a many-stakeholder study is evaluating how to yield the greatest grid benefits from electrified fleets.

NREL initiated a broad study of residential battery storage systems with Salt River Project utility in Arizona, which is collecting unprecedented data across demographics, device performance, and DER economics.

NREL's collaboration with Colorado-based cooperative Holy Cross Energy is offering the first-ever demonstration of advanced control algorithms developed at NREL. The control algorithms autonomously manage residential DERs and improve resilience by aggregating controllable assets into decentralised nodes.

NREL's Energy Systems Integration Facility

# SANDIA Upgrading HIL Capabilities

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation

Sandia National Laboratories

**Sandia National Laboratories** is a multimission engineering and science laboratory with major R&D responsibilities in the US national security, energy and environmental technologies, and economic competitiveness. The Distributed Energy Technologies Laboratory (DETL) of Sandia conducts research on generation, storage, and load management at the component and systems levels and examines advanced materials, controls, and communications to achieve a reliable, low-carbon electric infrastructure.

**infrastructure.der-lab.net/sandia**

Sandia's Distributed Energy Technologies Laboratory has recently added several capabilities. Low voltage, 0-120V 8 kW and high voltage 60-1100V 100 kW battery simulators were commissioned in 2019. Also, 100 interoperable microinverters were installed for power HIL simulations. A cyber-power co-simulation environment, called SCEPTRE, was integrated into the lab for adversary-based assessments of virtualised DER communication networks. Schweitzer Engineering Laboratories (SEL) relays have been integrated into HIL testing for demonstration of adaptive protection. Five grid-forming inverters (ranging from 2 – 100 kVA), SEL MicroGrid Controller RTAC 3555, and programmable high resolution 150 kW/150 kVar RLC load banks were added to the lab.

## New capabilities in 2020

Sandia is adding a 10 kW wind turbine generator to the laboratory for HIL experimentation. Additional grid simulators will be added for expanded HIL testing. Finally, new protection devices, including advanced reclosers and travelling wave relays, will be added.

## Consulting services

Sandia National Laboratories conducts world-class power systems research primarily for the U.S. Department of Energy but there are many options for external technology partnerships. Non-federal entities may enter into various agreements, such as Cooperative Research and Development Agreements (CRADAs), Strategic Partnership Projects (SPPs), etc. See **sandia.gov** for more information.

## Accomplishments

In 2019, Sandia completed a DOE SETO ENERGISE project that designed and implemented a Programmable Distribution Resource Open Management Optimisation System (ProDROMOS). In the project, the team created an Advanced Distribution Management System (ADMS) that measured power system operations to estimate the status of a feeder, forecast the distribution state over a short-term horizon, and issued optimal set point commands to distribution-connected equipment in order to regulate voltage and protect the system. This two-year project integrated multiple research innovations into an ADMS, designed to safely allow PV penetrations of 50% or greater.

Sandia has been developing new, advanced protection schemes for microgrids and distribution systems with high penetrations of inverter-based resources. These schemes include adaptive protection, settingless protection, incorporation of machine learning into relays, and model-based protection.

Power electronics research at DETL

Researching HIL capabilities across multiple laboratories during the SuperLab Demonstration

## Publications

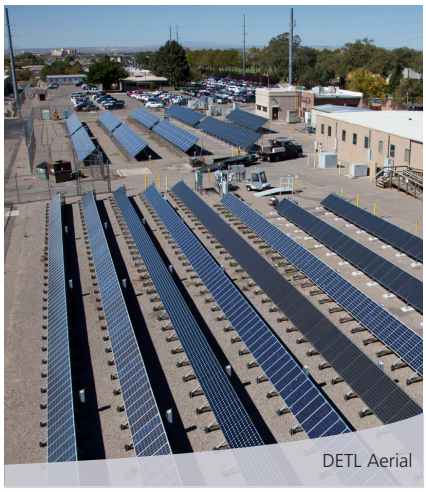

[1] N. Ninad, E. Apablaza-Arancibia, M. Bui, J. Johnson, S. Gonzalez, T. Moore, R. Heidari, W. Son, R. Bründlinger, R. Ablinger, C. Messner, C. Seitl, Z. Miletic, J. Hashimoto, K. Otani, I.V. Temez, F. Baumgartner, C. Fabian, B. Fox, S. Kumar, J. Kumar, "Development and Evaluation of Open-Source IEEE 1547.1 Test Scripts for Improved Solar Integration," EU PVSEC, Marseille, France, 9-13 Sept 2019.

[2] R. Bründlinger, J. Stöckl, Z. Miletic, R. Ablinger, F. Leimgruber, J. Johnson, J. Shi, "Pre-certification of Grid-Code Compliance for Solar Inverters with an Automated Controller-Hardware-In-The-Loop Test Environment," 8th Solar Integration Workshop, Stockholm, Sweden, 16-17 Oct. 2018.

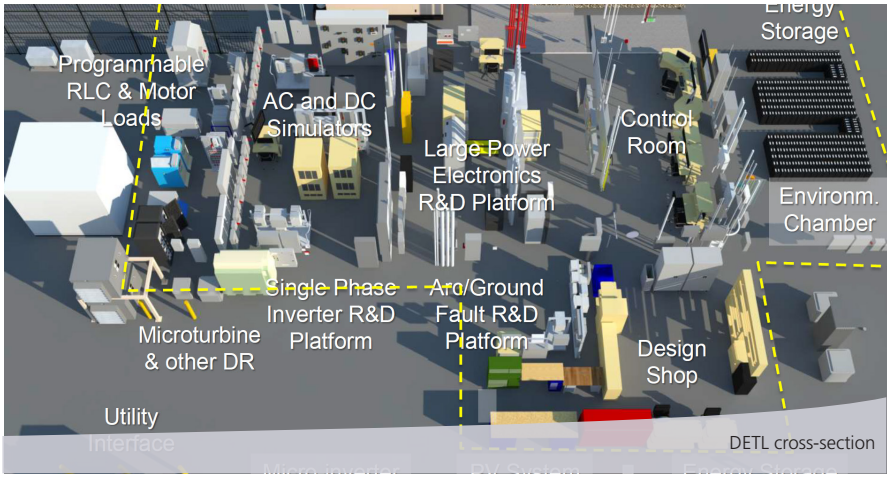
[3] J. Stöckl, Z. Miletic, R. Bründlinger, J. Schulz, R. Ablinger, W. Tremmel, J. Johnson, "Pre-Evaluation of Grid Code Compliance for Power Electronics Inverter Systems in Low-Voltage Smart Grids," 20th European Conference on Power Electronics and Applications (EPE'18 ECCE Europe), Riga, Latvia, 17-21 Sept 2018.

[4] J. Johnson, Z. Miletic, "Automated Interoperable Grid-Support Function Testing in a C-HIL Environment," Typhoon HIL Webinar, Vienna, Austria, 14 Mar 2019.


PV Simulator



DETL Aerial




DETL cross-section

# TNO Developing Open-Source Energy Modelling Language

- Microgrids & Distribution Network
- PV Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Grid / Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

TNO innovation for life

In the area of sustainability and energy, **TNO** works with commercial players and the government to develop and integrate knowledge of intelligent energy networks and smart grids. The focus lies on durable, balanced and cost-effective solution strategies for energy reduction, renewables integration and sustainability issues. Among the available facilities are a climate chamber, a nanolab, a cyber security laboratory, a sensor network living laboratory, a vehicle hardware-in-the-loop (VEHIL) laboratory, and the newly opened HESI facility.

**infrastructure.der-lab.net/tno**

In 2019 the HESI team developed the Energy System Description Language (ESDL), which is an open-source modelling language created for modelling the components in an energy system and their relations towards each other. Makers of energy transition calculation tools, simulations and GIS applications are encouraged to use ESDL in order to enforce the interoperability of their products.

In order to calculate the KPIs of an ESDL defined energy system, the HESI research team makes use of the Energy System SIMulator (ESSIM). An additional compute node allows running ESSIM simulations, or any other general-purpose virtual machines.

Furthermore, the HESI facility has extended its capabilities and now enables connecting devices to one of the flexible hot water buffers of 150 and 300 liters.

### New capabilities in 2020

Following up on an initial study, the HESI team intends to deploy a visualisation tool allowing more insight in the functioning of energy systems. The 200 displays intended to provide the multi-view experience are already installed in the lab, with the launch of the complete system coming in 2020.

Heat pump flex testing at the HESI facility

### Consulting services

- (Co-)simulation: quantifying the effects of introducing large numbers of renewables into the energy
- Flexibility testing with (hybrid) smart devices; study of the flexibility potential of devices such as batteries and hybrid heat pumps
- Implementation of relevant smart grid standards such as EN50491-12; helping manufacturers to conform to smart grid standards

### Accomplishments

TNO is a contributing member of CEN-CENELEC TC205/WG18, which defines the communication between smart devices and Customer Energy Managers. The architecture has been standardised in EN50491-12-1. Work continues on prEN50491-12-2 that defines the data model and the messages that are being exchanged.

## Research activities

**Hybrid Heatpump flexibility for congestion management:**

This study presented a high-level architecture for congestion management chain that was also verified in a proof of concept in TNO's Hybrid Energy System Integration (HESI) Facility. The test included 3 different hybrid heat pump models that are currently available on the Dutch market. It was shown in the lab that they can be controlled in a rudimentary way to switch from electricity to gas by making use of the Smart Grid Ready (SGR) interface.

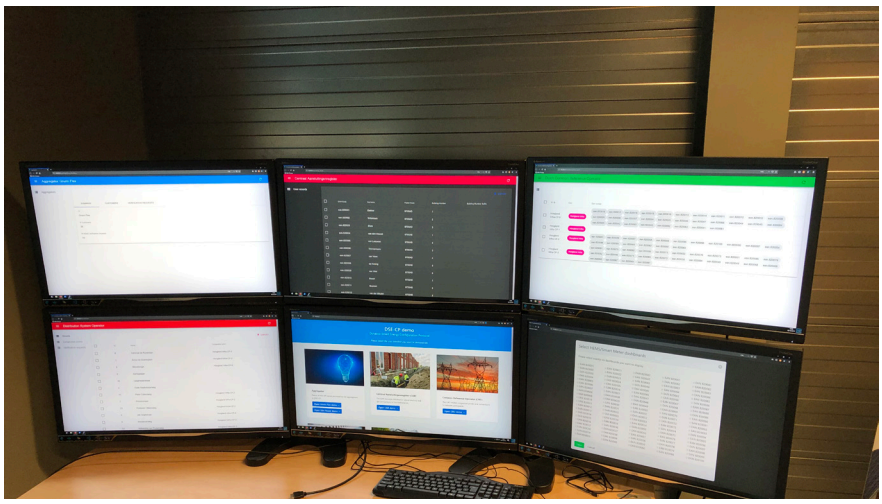
**Dynamic Smart Energy Configuration Protocol:**

In this project, a proof of concept was shown to verify the grid location of customers of an aggregator. It was proven that the existing smart meter infrastructure can be used for this purpose. Another objective of this project was for DSO to send temporarily connection limits to end-users in case of congestion. This mechanism also makes extensive use of the existing smart meter infrastructure.

## Partnerships

In the CoFlex project, ETPA (Energy Trading Platform Amsterdam), Stedin, Tennet and TNO cooperated in studying the possibility to mitigate congestion using transactive energy. The flexibility of devices of large consumers, for example in the greenhouse industry, is being traded on the energy marketplace to accommodate the needs of a DSO.

The HESI lab partnered with a consortium consisting of Enpuls, GasUnie, GasTerra, Ntra, Cogas, De Consumentenbond and Vereniging Eigen Huis to study the flexibility potential of hybrid heat pumps for congestion management purposes.

# Laboratory of Distributed Generation (LDG) at TU Lodz

- High Voltage & High Power
- Microgrid & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- HIL / Co-simulation
- Education & Training

Lodz University of Technology

The Institute of Electrical Power Engineering of Lodz University of Technology (**TU Lodz**) performs research on distributed generation (including renewables) and its integration with electrical power grid, quality of supply, microgrids, optimisation of network and power plant operation, electricity markets, power system modelling and simulation, as well as optimisation of lighting networks and devices.

**infrastructure.der-lab.net/tu_lodz**

In 2018-2019 TU Lodz performed the following upgrades in their LDG laboratory, which increased the functionalities of the infrastructure:

- The 50 kWh TPPL battery storage pack was connected to the DC network and ABB PCS100 converter
- The Capstone C30 gained new batteries for standalone operation and new generator
- The microturbine recuperation system got heat storage tanks
- New active power filter M10 ABB
- Additional RTDS GTAI/GTAO cards

Furthermore, the testing platform was built using RTDS system for evaluation of control strategies and testing the operation of prosumer installations with storage systems.

Leading the national project "Management of low voltage distribution network operation with prosumers' active participation", TU Lodz coordinates the project activities towards the development and construction of an integrated management system for voltage parameters control in LV distribution network using the regulatory capabilities of prosumer installations equipped with energy storage. In particular, these activities aim to achieve the following innovations:

- providing DSO with the ability to control the local generation and demand (preparing the local market for balancing)
- the activation of the prosumer in the network management

The project outcomes bring benefits to network operators, customers and prosumers and contribute to the development of the future network - intelligent microgrids.


Capstone C30 microturbine


Nexa fuel cell system

## New capabilities in 2020

The capability of the testing platform, based on RTDS system, will be increased for LV microgrids taking into account its different operation conditions (such as islanding or grid connected operation and increasing deployment of inverter based systems).

## Consulting services

- HIL and SIL tests for distribution network equipment and control algorithms (including protection automatics)
- Research on applications of energy storages in LV distribution networks and microgrids (improvement of energy efficiency, ancillary services)
- Interoperability evaluation of e-mobility systems
- Power quality issues, application of static compensators (e.g., STATCOM, APF, etc.)

## Research activities

TU Lodz is the leader of national funded project titled "Management of low voltage distribution network operation with prosumers' active participation". The other project partners are: PGE Dystrybucja S.A. (DSO), Lublin University of Technology, Apator Elkomtech S.A. (OEM).

The main aim of the project is the development and construction of an integrated management system for voltage parameters control in LV distribution network using the regulatory capabilities of prosumer installations equipped with energy storage.

## Partnerships

TU Lodz cooperates with Apator Elkomtech in the field of protection automatic using hardware (and software)-in-the-loop tests.

Switchgear board

# VTT Enhancing 5G Testing Facility

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

**VTT Technical Research Centre of Finland** is a globally networked multi-technological contract research organisation. VTT provides high-end technology solutions and innovation services that enhance the customers' competitiveness, thereby creating prerequisites for society's sustainable development, employment, and wellbeing.

**infrastructure.der-lab.net/vtt**

The ICT and 5G testing facilities at VTT were improved in 2018-2019 by commissioning a 5G test environment at the MultiPower laboratory, including several test networks and communication emulators, remote interconnection to the Oulu smart grid laboratory and automated remote control of distant 300 kW loads. Additionally, DC grid interface for residential customers, weather station adjacent to the PV station and continuously controlled load bank have been commissioned at the MultiPower laboratory. The control system is based on IEC61850 with GOOSE communication and other standard features. Time synchronisation has been enhanced by installing a fiber connection to the atomic clocks at VTT MIKES, the National Metrology Institute of Finland, providing the UTC maintained by Finland.

## New capabilities in 2020

In 2020, VTT is commissioning a real-time simulator RTDS to enable HIL testing via connection to the Cinergia grid emulator. A new smart metering, control and management system will be installed at the MultiPower laboratory to increase the number of control points and improve data logging. New substation automation and protection equipment will also be installed, completing the fully automated substation research environment.

Busbar at the Multipower Laboratory

## Consulting services

VTT provides wide consulting for research and development of systems and solutions for smart energy systems. VTT's infrastructure especially supports microgrid studies and ICT-related aspects. The research team is also able to integrate more detailed studies on storages, fuel cells and EV charging. Starting in 2020, the real-time simulator will expand VTT's research facilities.

## Accomplishments

The research environment has been successfully used within the Smart Otaniemi innovation ecosystem, which combines more than 50 partners into an active network of R&D actors.

## Research activities

Research on microgrid operation has taken place. As a part of laboratory development, interfaces and information models have been developed. Remote connections to other European laboratories have been developed and tested within ERIGrid project. Communication-related research utilising new communication technologies has also taken place.

## Partnerships

The new innovation ecosystem "Smart Otaniemi" has been initiated in 2018. The ecosystem consists of more than 50 partners, including companies and research organisations.

The Multipower laboratory serves as one research infrastructure for this ecosystem.

## Publications

An integrated pan-European research infrastructure for validating smart grid systems. Strasser, T. I., Pröstl Andrén, F., Widl, E., Lauss, G., De Jong, E. C. W., Calin, M., Sosnina, M., Khavari, A., Rodriguez, J. E., Kotsampopoulos, P., Blank, M., Steinbrink, C., Mäki, K., Kulmala, A., van der Meer, A., Bhandia, R., Brandl, R., Arnold, G., Sandroni, C., Pala, D. & 10 others, , 1 Dec 2018, In : Elektrotechnik und Informationstechnik. 135, 8, p. 616-622 7 p.

MP-relays

# KIT Energy Lab 2.0: PHIL Laboratory

- High Voltage & High Power
- Microgrid & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

Karlsruhe Institute of Technology

Karlsruhe Institute of Technology (**KIT**) is a public corporation pursuing the tasks of the Baden-Wuerttemberg state university and of a national research centre of the Helmholtz Association in the areas of research, higher education, and innovation. One key facility of KIT in the area of energy is the smart platform Energy Lab 2.0, which analyses interactions of different components of future energy systems to accelerate the German "Energiewende" (energy transition) and the integration of RES in electricity production.

**infrastructure.der-lab.net/kit**

KIT's Energy Lab 2.0 is an energy research platform allowing scientists to explore energy related questions of tomorrow. It enables investigations across energy sectors and carriers. The Smart Energy System Simulation and Control Center (SEnSSiCC) as part of the Energy Lab 2.0 studies future electrical power grids with a large share of distributed renewable energy resources. Apart from the PHIL Laboratory, which is set up and run by the Institute for Technical Physics, the SEnSSiCC hosts a Microgrid, a Data Analysis and Simulation facility, as well as a Control, Monitoring and Visualisation Center, which are operated by partners at KIT.

## New capabilities in 2020

After completion of the SEnSSiCC building construction in autumn 2018, the MVA PHIL Laboratory set-up has continuously advanced so that first PHIL experiments in a closed-loop setting were carried out at the end of 2019. Several 200 kVA amplifier modules are already in use and the support environment is installed, including the 20/0.4 kV power supply, primary and back-end distribution systems, a 60 kW water cooling system, measurement equipment and a resistive load-bank. The KIT team is investing further efforts to yield full access to all operational modes of the Laboratory and launch its full operation in 2020.

Site acceptance test of 200 kVA modules

Delivery of a flywheel energy storage system

## Consulting services

- Real-time model implementation, testing and verification (digital twins)
- Device testing in PHIL environments to ensure requirements and grid codes are fulfilled (realistic and safe)
- Grid measurements and recommendations for grid improvements
- Feasibility studies of new technologies based on superconductivity
- Technical readiness improvements of new power grid technologies

## Accomplishments

- Advances in establishing the PHIL infrastructures of the Energy Lab 2.0
- Completion of a feasibility study concerning the realisation and integration of a superconducting 380 kV-cable into the German transmission grid
- Best paper award at the IARIA ENERGY 2019 Conference for the presentation "Real-time Simulation and System Integration" that describes the set-up of the PHIL environments and results obtained by the PHIL Group at ITEP

## Research activities

Currently, research on the integration of combined-heat-power (CHP) systems into the low-voltage grid has started. This work aims at an optimal and versatile deployment of such facilities. CHP solutions based on a micro-gas-turbine and a piston-combustion engine are in the process of being setup and integrated into the PHIL facilities. Furthermore, digital twins, physical models, of the equipment have been implemented in the real-time environment.

Real-time implementations of benchmark and low-voltage distribution grids with adequate detail and complexity have been achieved. Long-term grid measurements have been conducted at substations of a distribution grid operator to find the best locations for energy storage components to support the grid operation and stability. For example, a location for a field test of a high-speed flywheel energy storage system has been determined. Measured data can be "played-back" in the PHIL environments to establish if an energy storage component suits the requirements and meets grid codes, e.g. VDE-AR-N 4105.

Several implementations of superconducting grid applications, e.g. superconducting cables and fault current limiters (SFCL), have been realised in the real-time environments. These are continuously updated and improved. An air-coil SFCL has been designed, built and successfully tested in a virtual grid at the 30 kVA Training-Station.

In 2019 a feasibility study concerning the realisation and integration of a superconducting 380 kV-cable into the transmission grid was completed.

KIT's Energy Lab 2.0

# Fraunhofer IEE Testing Renewable Integration and Inverter Dominated Grids

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Storage Systems
- E-Mobility
- Smart Grid / Buildings
- HIL / Co-simulation
- Education & Training

Fraunhofer IEE

The **Fraunhofer Institute for Energy Economics and Energy System Technology (Fraunhofer IEE)** explores solutions to technical and economic challenges in the transformation of energy systems in order to further reduce the costs of using renewable energy, to secure the supplies despite volatile generation, to ensure grid stability at the usual high level and to make the energy transition a successful business model.

**infrastructure.der-lab.net/**
**fraunhofer_iee**

To keep pace with the latest changes to grid codes and testing standards, the facilities of the SysTec laboratory have recently been upgraded with novel testing equipment. Fraunhofer IEE has designed and implemented an over-voltage ride through (OVRT) test container. The transformer-based OVRT testing equipment allows generation of short-term over-voltage events of up to 140% of nominal voltage and has a power capacity of 6 MVA. It was successfully set in operation in summer 2019. First tests have been accomplished with CHP units in the power range of several 100 kW.

## New capabilities in 2020

In 2020 the setup of a test field for the demonstration of a free spatial distribution of grid forming inverters will be realised. Therefore, different generators and loads are integrated in the test field. To prove the concept, the electrical distance of the grid forming inverters are varied as well as the grid topologies. Grid faults and asymmetric behaviour are part of the tests. The total rated power of the distributed generators is appr. 500 kVA.

OVRT container at SysTec, © Fraunhofer IEE

## Accomplishments

In 2019 Fraunhofer IEE gained re-accreditation (DIN EN ISO/IEC 17025:2005) in accordance with the latest test guidelines for the electrical properties of generation units, systems and components on low, medium, high and extra-high voltage networks (FGW TR3 Rev. 25 and DIN V VDE 0124-100).

## Consulting services

- Smart grid laboratory development (Reference Project: Electrobras CEPEL, Brazil)
- Modular training courses on grid integration of renewable energies (Reference course: Renewable Energy Management Centers – Training for System Operators, India)
- Grid code compliance testing Performance assessment of PV storage systems

## Research activities

In the project "Netzharmonie" the researchers of Fraunhofer IEE studied the propagation and interference of harmonic currents in the grid. Several measuring campaigns have been carried out involving large PV parks and wind farms. Based on this big data source, harmonic models were developed and analysed to study existing methods and develop new evaluation methods for harmonics.

The ongoing project "Netzregelung 2.0" aims at developing control concepts for grid forming inverters in inverter dominated grids, where the power quality and reliability will no longer be based on synchronous machines. In order to operate the future power system securely and stably, appropriate control algorithms and operation procedures have to be developed. The findings of "Netzharmonie" are being used to enhance the inverter models developed in the new project "Netzregelung 2.0" regarding harmonic emissions.

## Partnerships

The international project cluster INDORSE (Inverter Dominated Power Systems) kicked off with a workshop at the IRED 2018 in Vienna, intending to facilitate the international knowledge exchange and collaboration between research projects and to support pre-standardisation activities on the topic of inverter dominated power systems.

Fraunhofer IEE is active in standardisation activities on national and European level regarding testing of new grid code requirements (CLC TC8X WG03, FGW AK TR3, DKE K261.01). A two-year project was launched focusing on validation and improvement of testing procedures for grid code compliance of DER. Results of round-robin tests will be shared with standardisation committees.

## Publications

R. Bründlinger, T. Schaupp, G. Arnold, N. Schäfer, G. Graditi, G. Adinolfi, "Implementation of the European Network Code on Requirements for Generators on the European Level", 8th International Workshop on the Integration of Solar Power into Power Systems, October 16-17, 2018, Stockholm, Sweden.

Inside the OVRT container, © Fraunhofer IEE

# DER Management System at UCD

- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Education & Training

The Energy Institute of the **University College Dublin (UCD)** was established in 2012 and created a unique collaboration between academia and industry. The Integrated Energy Lab (IE Lab) is a one-of-a-kind facility at UCD for testing new solutions for a more interconnected and integrated energy system. It provides a place where industry and academics can work side by side to research, test and evaluate new solutions to strengthen clean energy innovation.

**infrastructure.der-lab.net/ucd**

The focus of UCD's IE lab is on experimentation and testing of the integration of new and developing energy technologies, with a particular focus on DER and smart control at the residential level. The facilities have been set up with the concept of energy system integration in mind to facilitate exploring interactions between different energy vectors such as electrical, thermal, gas, and their management in the system. Facilities in the lab include, real time simulation with HIL capability, temperature controlled room for thermal tests, gas (incl. hydrogen) and electrical test facilities.

## New capabilities in 2020

In the time frame of 2020 the IE lab will expand its capabilities with the addition of DER management system (DERMS) in collaboration with its partner EPRI. DERMS is intended to provide a management system for wide scale deployment of distributed generation and storage. It is also envisaged that capabilities will be expanded with the installation of an operator training system for transmission and distribution system management. The latest range of smart residential appliances along with smart gas and electrical heating system will also be included for testing with the management systems.

UCD Integrated Energy Lab temperature controlled room and thermal test facilities

## Consulting services

The IE Lab offers consulting services in a wide range of areas linked to the multi-disciplinary expertise of its academic members. Specific services include:

- Technology integration and interoperability assessment
- Advanced communications requirements
- Load management and system control considerations
- Enhanced building efficiency analyses
- Prototype refinement and pre-field validation of components
- Renewable electricity production and gas synergies
- Blended hydrogen and natural gas testing

## Accomplishments

The IE lab is a partner in the successful Horizon2020 project PANTERA, led by FOSS with the participation of other European partners, including DERlab members.

The UCD Energy Institute has also been nominated for a national Science Foundation Ireland Industry Partnership award.

## Research activities

In the context of nationally funded projects (ESIPP – Energy Systems Integration Partnership and ADEP – Active Distribution System Management using Power Electronics) research activities of the UCD Energy Institute have had a major focus on power system flexibility achieved through energy systems integration. This has had a focus on the provision of flexibility from storage, distributed generation, demand response in buildings, power to gas, and wastewater treatment systems.

In terms of lab testing, there has been a focus on the control and management of distributed energy resources, especially in the context of power systems with ever greater penetrations of renewable generation. A particular focus has been on the testing and validation of controls for system frequency support and virtual inertia from DER and grid forming techniques for inverter dominated systems.

## Partnerships

A highlight in 2019 has been the collaboration with other European partners, including several DERlab members in winning the PANTERA project. The developing partnership with the global network of smart grid research labs through the SIRFN network is also noteworthy. In addition to these, the lab has ongoing partnerships with a range of national companies through the research of the UCD Energy Institute, with particularly strong partnerships with ESB Networks, EirGrid, Ervia, AIB and SSE. Of note is the partnership which the lab has established with the Electric Power Research Institute.

# SYSLAB Becoming a Multi-Energy Distributed Control Research Facility

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- PV Systems
- Wind Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- HIL / Co-simulation
- Education & Training

The software infrastructure of the SYSLAB facility has been developed to ease the prototyping of controllers. The process automation ensures easy and robust deployment of distributed controllers on the 30+ control computers. A first version of a new development of a simulated/emulated system has been completed. This system includes a set of computers running the SYSLAB software stack and simulating components of the system. This will support the development of distributed controllers and their debugging before the controllers are deployed in the physical lab. This progress will support the development of distributed controllers and their testing by providing a path from a simulation environment via emulated control infrastructure to deployment in the physical lab.

Another major development has been the installation and commissioning of the heat switchboard with an associated software stack for the control and automation - FlexHeat system. This forms a small local district heating system with coupling to the power system via booster heaters and heat pumps. This allows for more complex controllers to be implemented and tested for multi-energy systems.

Finally, the Digital Energy Lab has been initiated. This facility will store data from many research and development projects and make them available for further research. It also provides capabilities for online use of data for control purposes.


SYSLAB

SYSLAB of the **Department of Electrical Engineering of the Technical University of Denmark (DTU)** is a flexible intelligent DER laboratory. Among other DTU's facilities are the Center for Electric Power and Energy (CEE), which aims to transform the electric power system into a reliable, cost-efficient and sustainable system based on renewable energy, and the Electric Vehicle Lab (EV Lab), which supports a wide array of EV integration and technology services.

**infrastructure.der-lab.net/dtu**

### New capabilities in 2020

In 2020 SYSLAB will be extended with a district heating system connecting five of the existing SYSLAB buildings. The district heating system will mirror the electricity system in terms of layout and control. The district heating system will include solar collectors, hot water tanks and coupling components as well as controllable loads. It will integrate with the intelligent building control. SYSLAB will also have a gas infrastructure for power to gas/hydrogen. These upgrades will turn SYSLAB into a multi-energy distributed control research facility and will enable the development of cross-domain control concepts.

There will be a tighter integration between the various PowerlabDK infrastructures, primarily the large RTDS cluster/amplifier and the Digital Energy Lab. This will establish a combined facility that can do HIL and up-scaled tests concurrently.

### Consulting services

PowerlabDK facilities support testing of distributed control schemes and of DER components in a real distributed lab with a focus on the unit control. Additionally, PowerlabDK offers access to real time simulation system for large system investigations.

### Accomplishments

SYSLAB has been used for testing several controller concepts for the integration of DER units in the overall control of the power system and flexibility: distribution network flexibility and congestion management, distributed and centralised voltage control, as well as the active coordination of heat assets including heat storage and heat pumps. A new topic has been the investigation of loss-of-mains protection of PV inverters.

### Research activities

A major test case involving industrial systems was executed via the ERIGrid project. A coordinated voltage control solution was tested using SYSLAB to its full extent: the controller coordinated and communicated with tap-changing transformer (two 11/0.4kV transformers installed in a back-to-back configuration) and about 16 actively controlled diverse assets (incl. PV, load banks, storage, EV, etc.). The test cases included the emulation of both rural and urban feeder configurations cables. Extensions for interconnecting SYSLAB with other laboratories, as well as real-time simulations have been prototyped. With the establishment of remote communication to SYSLAB via the JanDER and VILLAS laboratory coupling technologies, a milestone is achieved toward the integration of European

# PNDC Upgrading Communications Testbed for Distribution Network Testing

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
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- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

UNIVERSITY of STRATHCLYDE
POWER NETWORKS DEMONSTRATION CENTRE

**Power Networks Demonstration Centre (PNDC)** is a research and demonstration facility at the Institute for Energy and Environment (InstEE) of the **University of Strathclyde**. The main areas of research are asset management, communication and systems integration, network and demand-side management, power electronics and distributed energy, protection and control, sensors and measurement.

**infrastructure.der-lab.net/**
**uni-strathclyde**

In 2019 the PNDC enhanced its 11kV distribution network test environment. This includes increasing the scope of the fault throwing capability, to now include the introduction of intermittent ('pecking') faults on PNDC's LV network. The communications testbed now includes the latest in secure networking, including industrial firewalls and intrusion detection software. This has allowed PNDC to deliver projects such as penetration testing of specific network assets, utilising both physical and virtual networks. Additionally, PNDC has supported the testing of asset discovery tools for use in distribution network environment.

## New capabilities in 2020

Moving ahead into 2020, the facility will begin to expand its capability within multi-vector energy systems. This will include the demonstration and integration of systems across electricity, heat, and transport. The PNDC will also establish a platform for the testing of distribution network 'ancillary services', which will support the transition of DNOs in the UK towards becoming DSO in the future. This will build on existing capability within the facility, including real-time simulation and hardware in the loop (PHIL) testing. PNDC's ability to demonstrate 'real-world' scenarios for future DSO operations will provide insight into future demand side management and flexibility requirements.

EV charging at PNDC

### Consulting services

Outside the DERlab network, the PNDC provides a range of services to both existing and new clients, including utilities and technology developers. This includes the delivery of applied research through an industrially funded programme, and engaging in testing and demonstration activity which utilises PNDC's unique energy network infrastructure.

### Accomplishments

The PNDC has supported a number of key innovation projects led by electrical network operators and manufacturers alike. The research team begun working to support the transformation towards greater levels of electrification within transport and heat sectors, and will look to establish further capabilities in these areas.

# Uni Strathclyde Expanding Microgrid and Decentralised Control Infrastructure

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University of Strathclyde Glasgow

Distribution Network and Protection Laboratory (**D-NAP**) is a research facility of the **University of Strathclyde** that comprises a 100 kVA microgrid set with real-time simulation and HIL capabilities. The research objectives of D-NAP are demonstration of new techniques for distributed power system control, analysis of the effects of components within a system, and testing of protection systems/devices.

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In 2019, the laboratory team at the University of Strathclyde added significant hardware to the microgrid infrastructure, including: lithium-ion battery storage (10 kVA), supercapacitor energy storage (192 kW peak power), and their corresponding interfacing converters.

A new RTDS NovaCor and Aurora link enable larger-scale simulations and high fidelity PHIL demonstrations. A unique platform for wide-area monitoring, protection, and control with 64 PMUs has been developed, where PMU algorithms execute on a cluster of Raspberry Pis with waveform data from real-time simulations using GTFPGA unit.

The laboratory has a real-time link to several research infrastructures across the world, including Nokia Laboratory in USA and Rolls-Royce Corporate lab in Singapore.

## New capabilities in 2020

A major planned upgrade will involve integration of DC network capabilities for grid, railway, marine, and aerospace applications.

A system for providing UK-wide grid monitoring is being developed. The data will be real-time (from distributed PMUs) and publicly available, to provide new insights into grid operation and opportunities for data analytics. The prototype website is available at **smartgridmvp.eee.strath.ac.uk**.

The geographically separated real-time simulation capability, currently limited to real-time simulations and CHIL only, will be expanded to incorporate PHIL. This will enable large-scale system level studies to be undertaken harnessing capabilities of pan-European smart grid laboratories.

64 PMUs


Battery and supercapacitor

## Consulting services

- Guidance for national engineering recommendations on the impact of loss of mains protection and converter control in future system scenarios
- Systems-level validation and demonstration, including microgrid controllers, advanced marine electrical systems, and distributed optical sensing for power systems

## Accomplishments

- Approximately 30 papers published
- New methods for grid frequency control with high levels of DERs
- Method for accurate PMU reporting latency measurement
- New approaches for PHIL experiments

## Research activities

Frequency control: fast-acting, decentralised frequency control has been demonstrated within both national and international programmes. This has impacted future TSO capabilities for system reserves.

Wide-area protection: development of new techniques and demonstration in a distributed optical sensing platform with a spin-out company (Synaptec).

Measurements: new techniques for power quality analysis in DC railway systems, which will impact future measurement standards.

## Partnerships

- New Nokia lectureship position established
- Extended partnership with Rolls-Royce in the area of marine electrical systems
- New collaboration with Rolls-Royce Corporate Lab, Singapore.
- New collaboration with Virginia Tech, USA

## Publications

[1] Syed, M. H., Guillo-Sansano, E., Blair, S. M., Burt, G. M., Prostejovsky, A. M., & Rikos, E. (2019). Enhanced load frequency control: incorporating locational information for temporal enhancement. IET Generation, Transmission and Distribution , 13(10), 1865-1874.

[2] Stübs, M., Dambrauskas, P., Syed, M. H., Köster, K., Federrath, H., Burt, G. M., & Strasser, T. (2019). Scalable power system communications emulation with OPC UA. Paper presented at The 25th International Conference and Exhibition on Electricity Distribution, Madrid, Spain.

[3] Hong, Q., Nedd, M., Norris, S., Abdulhadi, I., Karimi, M., Terzija, V., Booth, C. Fast frequency response for effective frequency control in power systems with low inertia. 1-8. Paper presented at The 14th IET International Conference on AC and DC Power Transmission, Chengdu, China.

[4] Hong, Q., Nedd, M., Norris, S., Abdulhadi, I. F., Karimi, M., Terzija, V., Booth, C. (2018). Fast frequency response for effective frequency control in power systems with low inertia. The Journal of Engineering.

# TECNALIA Providing Cybersecurity Testing

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In 2019 TECNALIA launched its new Smart Grid Cybersecurity Laboratory, which provides a safe and controlled environment to simulate cyberattacks on smart grid infrastructures. It is composed of a DSO control centre, and a primary substation.

The control centre includes an IEC-104 SCADA and a LDAP & NTP servers. The primary substation is composed of a SCU, HMI, several IEDs, redundant communications (PRP), and analogic/digital signals and sampled values generators.

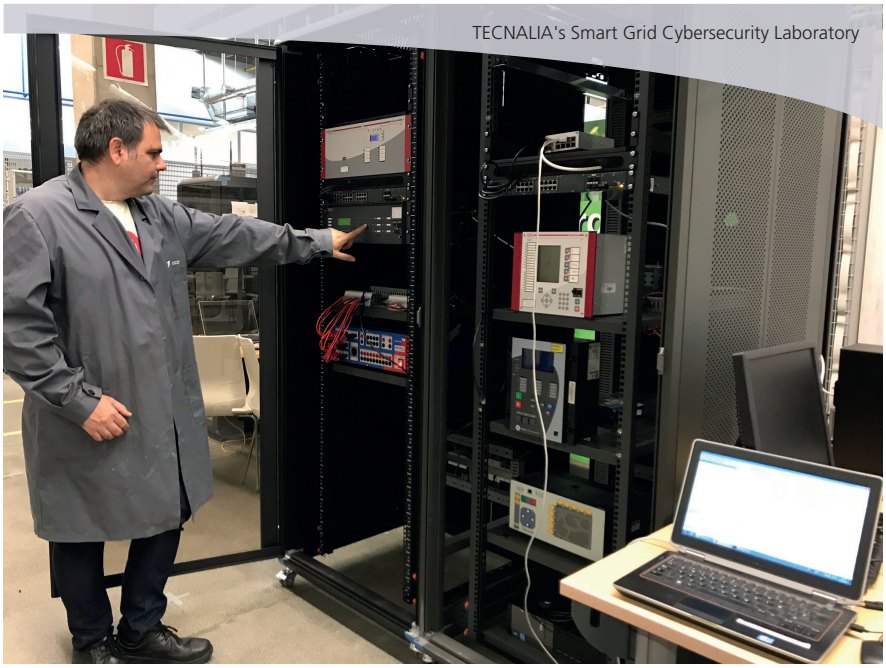
The laboratory allows to generate data traffic in different industrials protocols: IEC 61850, IEC 60870-5-104, DNP3, LDAP (LDAPS), NTP (NTPS), FTPS, Telnet, SSH, WS, and others.

## Consulting services

TECNALIA's Smart Grid Cybersecurity Laboratory provides a secure and controlled environment to perform ethical hacking (on simple devices or on the whole network), deploy tools for attack discovery, test the countermeasures and its substation/DSO side-effects, assess the impact of the infected and bugged equipment, etc.

## New capabilities in 2020

In 2020 TECNALIA will further incorporate its Data and Protocol Cybersecurity Laboratory. The facility provides a safe and controlled environment for certifying and verifying the correct functionality and cybersecurity for type-testing of smart grid products. It is composed of different servers, power sources, loads, network simulators, relays, switches, gateways and a home-made testing tool to check if the equipment under tests comply with the standards or the requirements defined by the utilities or final clients.



TECNALIA's Smart Grid Cybersecurity Laboratory

tecnalia Inspiring Business

**TECNALIA** Research & Innovation offers technological services, testing and certification, R&D&I projects, transfer of industrial property, business promotion, business diversification, innovation management and foreign support. Among many other experimental facilities, the Energy and Environment Division includes a Smart Grids Area, a High Power Laboratory, a High and Low Voltage Laboratory, and a Distributed Energy Resources Laboratory equipped with several types of generation, storage and controllable loads, including an electric vehicle platform and a smart metering test bench.

**infrastructure.der-lab.net/tecnalia**


TECNALIA's Smart Grid Cybersecurity Laboratory

## THOR Laboratory

The core of THOR Laboratory is a 4-quadrant fully programmable voltage source in the power and voltage ranges of up to 1.25 MW and 3300 V respectively. Frequency variations of the output voltage from 0 to 75 Hz as well as generation of programmable sets of voltage harmonic components up to the 10th harmonic are possible. The flexible grid can be used as a grid emulator to test power converters. Possible equipment for tests are: Wind converters, energy storage converters, traction converters and grid power quality devices like STATCOMS, FACTS or active filters. A SCADA system controls the lab's parameters. The following cases can be investigated at THOR Laboratory:

- Voltage and frequency variations
- Reactive power control behaviour
- Active power control behaviour
- Faults
- Harmonics
- Flicker

Furthermore, a new walk-in high-low temperature test chamber is included:

- Test space dimensions (WxHxD): 2640 x 2400 x 4160 mm
- Temperature range: -45- to 85-
- Humidity range: 10% to 95% RH

## Centre for Development and Demonstration of DER Technologies (Microgrid)

Coupled to the 30 kV radial network, the microgrid formed by different generation, storage devices, loads, with a manageable power of 200 kVA. The facility deals with the connection, integration and validation of technologies related to DER including EV, as well as with the operation and control strategies of the entire microgrid.

## Publications

[1] I. López, S. Ceballos, J. Pou, Senior Member, IEEE, J. Zaragoza, Member, IEEE, J. Andreu, I. Kortabarria and V. G. Agelidis, Senior Member, IEEE:
Modulation Strategy for Multiphase Neutral-Point-Clamped Converters
IEEE Transactions on Power Electronics, February 2016, Vol. 31, nº 2.

[2] I. López, S. Ceballos, J. Pou, Senior Member, IEEE, J. Zaragoza, Member, IEEE, J. Andreu, E. Ibarra and G. Konstantinou, Member, IEEE:
Generalised PWM-Based Method for Multiphase Neutral-Point-Clamped Converters With Capacitor Voltage Balance Capability
IEEE Transactions on Power Electronics, June 2017, Vol. 32, nº 6.

# CRES Enhancing the Microgrid

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Storage Systems
- Smart Buildings
- ICT
- Education & Training

ΚΑΠΕ
CRES

The **Centre for Renewable Energy Sources and Saving (CRES)** is the Greek organisation for RES, RUE and energy saving (ES). Its main goal is research and promotion of RES/RUE/ES applications at national and international levels, as well as support of related activities in the context of sustainable development. CRES offers applied research and technical support to RES sectors such as geothermal energy and active solar systems amongst others.

**infrastructure.der-lab.net/cres**

In 2018 and 2019 CRES upgraded the SCADA system of the experimental microgrid. The newly installed software allows the interconnection of the existing SCADA with Matlab/SIMULINK, enabling the testing and evaluation of more complex control algorithms while also allowing the incorporation of simulation models in the physical system. The first systematic application in this direction is an experimental implementation of a remote lab application for the needs of the H2020 project ERIGrid. The specific application simulates parts of the microgrid, i.e. PVs and environmental conditions, and controls the operation of storage and loads in real time.

## Consulting services

- Characterisation of PV systems including cells, modules and inverters in terms of efficiency, conformance to standards etc.
- Characterisation and conformance to standards testing of various battery technologies including Lead-Acid and Li-ion batteries
- Performance evaluation of DER technologies, microgrids operation, smart grid controllers and power quality issues in distribution grids

## New capabilities in 2020

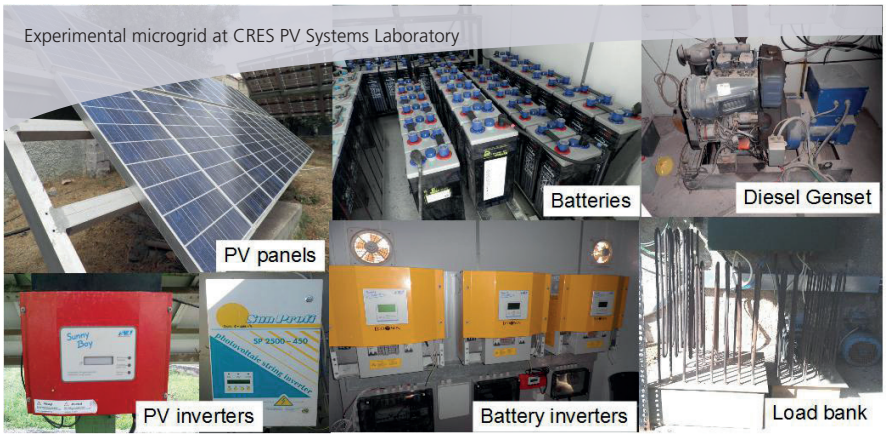
In 2020 CRES will upgrade specific power components of the microgrid by replacing obsolete inverters with new ones. One of the plans is specifically to install a photovoltaic inverter that allows the control of reactive power in order to study the influence of these devices on distribution grids.

Furthermore, CRES will carry out additional upgrades to the existing SCADA system of the microgrid.

Last but not least, CRES is planning to upgrade the laboratory equipment for performing various types of diagnostics on PV modules.

## Accomplishments

After the successful completion of the ELECTRA IRP project, CRES, in collaboration with the EERA JP Smart Grids applied for the Web-of-Cells trademark. In addition, after the successful completion of the PRISMI project, CRES presented and published a load flow analysis tool for use in island power systems.



Experimental microgrid at CRES PV Systems Laboratory

## Research activities

Through involvement in various research projects over the years 2018-2019 CRES has developed, tested and validated various methods and tools related to grid planning and operation. During the last stage of ELECTRA IRP CRES refined and tested control algorithms related to balance/frequency control that revolutionise the operation of power systems.

During the same period, in the frame of the PRISMI project, CRES developed a tool that facilitates the load flow analysis of island grids. The specific tool, combined with a set of methods developed in the project, allow designers to optimally plan the operation of power systems with high RES penetration.

In the ERIGrid project, CRES contributed in the development of Harmonised Testing Procedures for smart grids which allow a systematic testing approach in this field. Also for the same project, CRES implemented experiments related to power quality of microgrids, performance of li-ion battery storage systems and remote lab applications.

All these experiments contributed to the development of new techniques for the optimal operation of DER technologies and smart grids. Last but not least, in the frame of the project GIFT CRES is leading the Scalability and Replicability Analysis of smart grid technologies implementation on geographical islands.

## Partnerships

During 2018-2019 as member of the ERIGrid consortium, CRES was involved in the finalisation and evaluation of testing procedures developed in the project. Moreover, CRES developed a remote lab application for educational purposes, hosted and successfully implemented three Transnational Access projects.

CRES is also a member of the GIFT consortium, an Innovation Action project aiming at demonstrating smart grid solution on geographical islands. In this project, CRES is leading the task of Scalability and Replicability Analysis. Finally, as a member of the EERA JP Smart Grids, CRES is active in various research and networking activities in the EERA context.

## Publications

[1] M. H. Syed, E. Guillo-Sansano, S. M. Blair, G. M. Burt, A. M. Prostejovsky, E. Rikos, "Enhanced Load Frequency Control: Incorporating Locational Information for Temporal Enhancement", IET Generation, Transmission and Distribution, Vol. 13, Issue 10, 21 May 2019, p. 1865 – 1874.

[2] M. Cabiati, E. Rikos, A. Guagliardi, R. Lazzari, "Experimental validation of Adaptive FCC and BRC functionalities for the proposed ELECTRA Web-of-Cells", CIRED 2018 Workshop 2018 on microgrids and local energy y communities, Ljubljana-Slovenia, June 7-8, 2018, paper no. 227.

[3] H. Saelle, A. Morch, E. Rikos, S. M. Canavese, M. Kosmecki, "Utilisation of distributed energy resources' flexibility in power system operation – Evaluation of today's status and description of a future concept", 53rd International Universities Power Engineering Conference, UPEC 2018, Glasgow-Scotland, September 4-7, 2018, paper no. 329.

# RSE Enhancing the Digitalisation of Test Facilities

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Biomass / CHP Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation

**RSE** SpA (Ricerca sul Sistema Energetico) carries out publicly funded national and international programmes in the fields of electrical power, energy and the environment. RSE conducts research in three main areas: all aspects linked to the sustainable development of the Italian electrical power network and related infrastructures, the safe and effective use of primary sources of energy, as well as power generation, transport and distribution, and end-use energy efficiency.

**infrastructure.der-lab.net/rse**

In 2018-2019 RSE incorporated new laboratories and new components:

- IoT-Big Data laboratory: The laboratory is designed for research on Big Data, cloud computing and IoT, monitoring and control of smart grid, smart home and sustainable mobility. The main purpose of this laboratory is to facilitate collaborative work of researchers coming from different scientific fields.
- Real Time Simulation Lab: The laboratory is based on a real-time digital simulator produced by OPAL-RT. The simulator is equipped with I/Os for the interfacing of real systems to fulfil "HIL" simulations.
- Improvement of the DER Testing Facility (DER-TF): The DER-TF was extended with two V2G charging stations, a new high temperature Nickel-Sodium energy storage system and the completion of the LVDC microgrid.

RSE produced publications on a range of topics, such as:

- Testing control algorithm for microgrids, both grid-connected and islanded
- Model-predictive control for AC and DC microgrids
- Control of DC microgrids' converters
- LVDC hybrid circuit breaker and DC fault analysis
- Microgrids aggregation for ancillary services
- Smart grid semantic platform

## New capabilities in 2020

It is planned to further develop the DER-TF through the realisation of a simplified district heating distribution grid with controllable energy conversion units and the integration of power-to-gas units. This will enable studies of multi-energy systems and improve the capabilities for testing in a lab scale system that includes power-to-heat and power-to-gas flexibility.

Furthermore, the electrical distribution grid will be enhanced with the realisation of a MVAC ring and a multi-terminal LVDC grid enabling new testing capabilities.

## Consulting services

- Characterisation of PV modules, batteries and distribution grid components and development of advanced diagnostic tools
- Development and test of control algorithms for microgrid, VESS and V2G
- Development of applications for cloud computing, IoT and Big Data/ Artificial Intelligence
- Institutional support

RSE's IoT lab

## Research activities

The DER-TF has been used for the demonstration of the Microgrid island operation, considering both the power converters control and the control algorithms for the island transition, the island management and the main grid resynchronisation. The activity has demonstrated that the use of Grid-forming converters allows the transition and stable operation of the islanded microgrid. During island operation, secondary and tertiary controls permit the voltage and frequency regulation and restoration and the optimal management of all the resources. The island operation can be stably maintained for a long time, resorting to grid-forming converters and suitable controls, but it is necessary to integrate some new functionality in the loads and in the renewable generator to reduce their power in a critical situation. Finally, the DER-TF has been used for the experimental verification of a Hybrid AC/DC microgrid operation, considering also the fault conditions.

The activity has demonstrated the operation of this grid in different conditions, like the management of a hybrid AC/DC microgrid, the DC microgrid island operation and the possibility of feeding a secondary AC subgrid through the DC microgrid. DC microgrids can improve the energy efficiency, provide an easier integration of energy resources and loads and offer services and flexibility to the AC grids. Furthermore, a new hybrid circuit breaker for DC grids has been proved through experimental tests demonstrating the ability to solve some issues related to the protection methods of such grids.

The IoT-Big Data lab has been used to develop software applications for the energy sector. One of these is the Smart Grid Semantic Platform, a microservices architecture useful to integrate different electrical grid aspects. The platform uses a semantic data store based on the standard IEC CIM and stores the topological information, assets, geographical information and measurements. The platform is empowered to create a digital twin of the electrical grid and is easily upgradable with new microservices.

The real-time Simulation Lab activity has been focused on CHIL (Control Hardware in The Loop) simulations of coordinated series and shunt compensators (Open-UPQC), also including energy storage systems; this work has been developed as a case study to those devices into a low voltage distribution grid, evaluating system performances for suppling sensitive loads. Furthermore, the real-time lab has been used to study the automatic reconfiguration of MVDC grids, and for the protection of electrical parameters and devices. The study included Optimal Power Flow (OPF) calculations on a sample grid and real-time control of power electronic converters to face faulty events, even the loss of multiple nodes of the system. Finally, real-time tests have been performed to verify design and control logic performances of an integrated solid-state breaker-limiter in managing fault conditions in meshed MVDC networks.

## Partnerships

- EnelX and Nissan within the scope of V2G integration and demonstration
- Evolvere and EnelX in to aggregate residential energy storage system to provide flexibility services
- Unareti (DSO) to connect and integrate the DER-TF with a new A2A's laboratory in order to analyse the integration of different smart grid apparatus
- Unareti (DSO) to analyse distribution grid data analysis (Big Data and IEC CIM 61968-61970)
- Terna (TSO) to analyse different scenarios for the Italian grid and develop control algorithms for the grid
- BDF digital, a converter manufacturer, to develop and demonstrate innovative solution to improve the Maximum Power Point tracking in PV plant
- Politecnico di Milano to understand and predict the electric consumption patterns in the short, mid and long-term, at the distribution level (energy forecasting analysis)
- RWTH Aachen University to develop IEC CIM 61968-61970 for network models

# FOSS Enhancing Smart Grid Analytics for Advanced Energy Landscapes

- High Voltage & High Power
- Microgrids & Distribution Network
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- PV Systems
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- Education & Training

FOSS
Research Centre for Sustainable Energy

The **Research Centre for Sustainable Energy (FOSS)** of the University of Cyprus strives to be a regional R&I hub of excellence as well as an international state-of-the-art training and education centre. FOSS focuses its research on renewable energy sources with an emphasis on solar energy but has also expertise in energy efficiency and smart electricity grid.

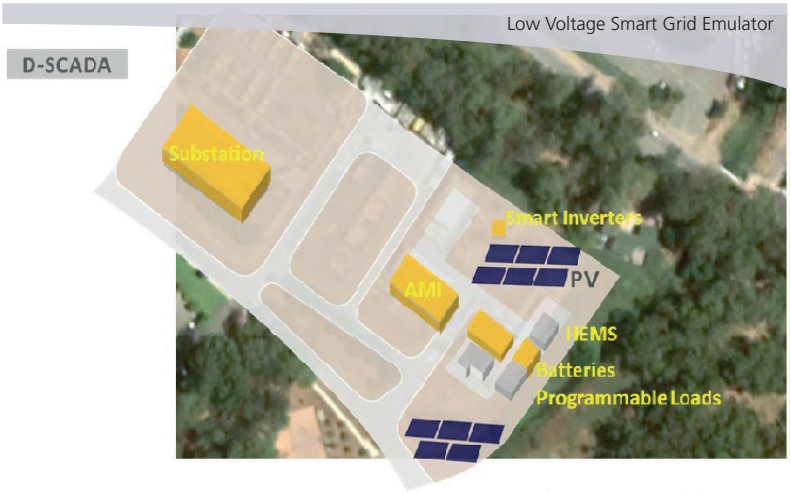
**infrastructure.der-lab.net/foss**

In 2018-2019 FOSS performed the following upgrades:

- Low Voltage Smart Grid Emulator: a flexible and scalable R&D smart grid infrastructure that is fully equipped with distributed generation test benches, battery storage, DC and AC programmable loads, smart meters, data acquisition devices and a home energy management system
- PV power production forecasting platform: a web-based tool that calculates the forecasted power of PV systems (point and aggregated sites day- and hour-ahead forecasts)
- Indoor PV PID testing: the infrastructure comprises a HV source-meter, data-acquisition system and environmental chamber for indoor PID tests according to IEC 62804

## New capabilities in 2020

- Energy analytics and power flexibility lab: FOSS will implement a new lab that will be fully equipped with a real-time simulation platform and a centralised decision controller for advanced distribution management
- Virtual power plant (VPP) emulator: The existing forecasting platform will be extended by integrating a pilot AMI network of 300 prosumers to implement a simulation tool to emulate functionalities at different power dispatch operations
- Microgrid: FOSS leads the design and implementation of the University of Cyprus microgrid that will operate the University in an autonomous and cost optimal manner




## Consulting services

- Integration of DER, standards and grid codes
- PV production forecasting (day- and hour-ahead) and load forecasting (short-term)
- Interoperability and communication testing
- Assessment of demand response in future smart grids

## Accomplishments

- EU LIFE 2019 Citizens Award to "SmartPV" project for smart net metering promotion and cost-efficient PV integration in Cyprus
- NREL PV Reliability Workshop 2018 Award for innovative work in the area of online failure diagnosis of PV
- Cyprus Seeds 2019 Innovation Fund for sensors that detect faults in PV systems

## Research activities

Implementation of novel forecasting algorithms to achieve hourly averaged PV power production day- and hour-ahead forecasting accuracies less than 5 % root mean square error (RMSE) relative to the nameplate power for single plants and less than 4.5 % at a regional aggregated level. Forecasting algorithms are integrated in a unified cost-effective solution that provides increased accuracy beyond the state-of-the-art with the use of advanced data analytics, which is required by system operators participating in both energy trading (ET) and grid support (GS) services (absolute improvement of 2 % compared to published results).

Design and implementation of first energy storage system pilot in Cyprus comprising of 20 prosumers installed with decentralised storage units and a centralised storage system at the substation level of a LV distribution feeder. Initial research results showed that over 70% of the total energy consumption of the residential prosumers can be obtained from the PV and battery combination (increasing significantly the self-consumption ratio).

## Partnerships

FOSS is now a participant of the ERIGrid 2.0 project which is the largest European research infrastructure collaboration supporting smart grid and smart energy systems research, technology development, validation and roll out.

## Publications

[1] P. Ingenhoven, G. Belluardo, G. Makrides, G. E. Georghiou, P. Rodden, L. Frearson, B. Herteleer, D. Bertani, D. Moser, "Analysis of photovoltaic performance loss rates of six module types in five geographical locations" IEEE Journal of Photovoltaics, vol. 9, no. 4, pp. 1091–1096, Jul 2019.

[2] D. Moser, D. Bertani, A. J. Curran, R. H. French, M. Herz, S. Lindig, G. Makrides, B. Müller, M. Richter, M. Van Iseghem, W. van Sark, and J. S. Stein, "International collaboration framework for the calculation of performance loss rates: data quality, benchmarks, and trends", in 36th European Photovoltaic Solar Energy Conference, 2019.

# Real-Time Controlling and Monitoring at EES-US Group

- High Voltage & High Power
- Microgrids & Distribution Network
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- Power Quality & EMC
- PV Systems
- Wind Systems
- Storage Systems
- E-Mobility
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- Education & Training

The **Electrical Energy Systems Group of the University of Seville (EES-US)** carries out multiple research activities in power engineering and maintains strong connections both with the national industry and other research groups worldwide. EES-US covers a broad range of research topics, among which are energy efficiency and power quality, computational and simulation tools for power systems, renewable energy control and integration, and the contribution of distributed generation to ancillary services.

**infrastructure.der-lab.net/ees-us**

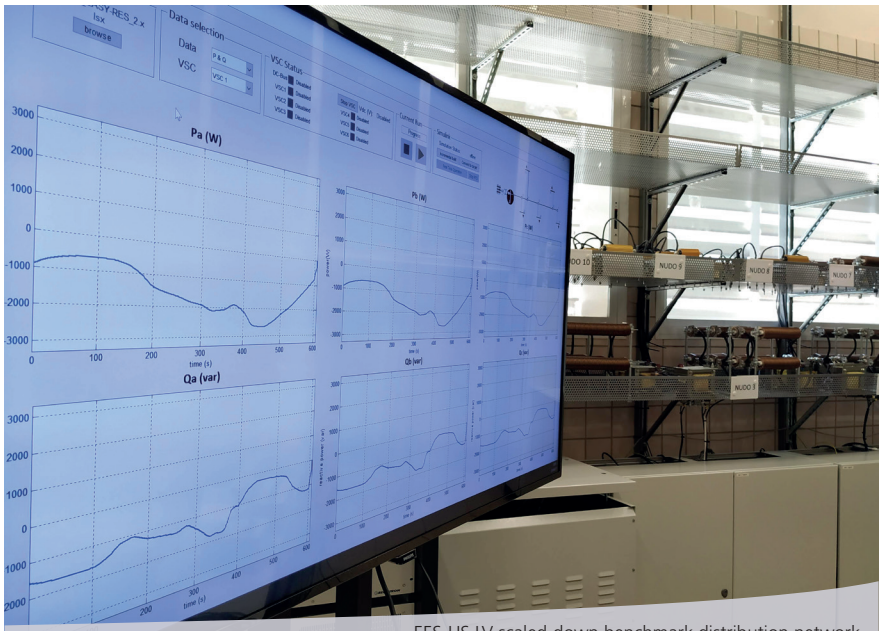
In 2018 and 2019 the EES Group of the University of Seville acquired a power amplifier Regatron TC.ACS in addition to their OPAL-RT 5600 and HIL402 Typhoon platforms. With this 50 kVA, full four-quadrant, three-phase and four-wire unit, the EES Group has extended their capabilities to PHIL testing.

Furthermore, the EES Group reproduced a scaled-down version of the LV benchmark network proposed by the CIGRE Task Force C06.04.02 in order to analyse the impact of the distributed generation. The distribution system is a three-phase four-wire network fully configurable, controllable and monitored in real-time.

## New capabilities in 2020

The EES-US Group has a laboratory with a full-scale secondary substation with two dry transformers 20/0.4 kV, 400 kVA and related switchgear. It is planned to incorporate new elements and develop a full-scale testing facility for automated testing of electronic on-load tap changers (OLTCs).

It is also planned to expand the functionality of the already existing LV AC scaled-down system by incorporating DC distribution lines. The objective of this hybrid AC/DC scaled-down distribution system is to integrate all the new DC agents (electric vehicles, photovoltaic generation, battery energy storage systems) within the DC side of the network to optimise its real-time operation.



EES-US LV scaled-down benchmark distribution network

## Consulting services

- Optimal planning of wind farms based on NPV maximisation
- Optimal operation of large-scale wind and PV farms
- Wide-area control using PMUs for enhancing stability margins
- Integration of electronic on-load tap changers for distribution transformers
- Ancillary service provision by distributed generation
- Integration of power electronic devices for maximising the penetration of EVs and distributed generation

## Accomplishments

In 2018-2019, the ESS-US Group has published or patented the main outcomes of their research activities, among others:

- A. Gómez-Expósito et al., "City-Friendly Smart Network Technologies and Infrastructures: The Spanish Experience", Proceedings of the IEEE, vol. 106, no. 4, pp. 626-660, April 2018
- J.M. Maza-Ortega et al., Static on-load tap changer for transformers with discontinuous regulation windings, PCT/ES2019/070363

## Research activities

During 2018-2019 the ESS-US Group has been involved in some research projects dealing with grid planning and operation of power systems:

- EASY-RES (Enable Ancillary Services by Renewable Energy Sources) funding: H2020 Grant Number 764090. EASY-RES will develop novel control algorithms for converter-interfaced DRES and storage systems to enable them to provide inertia, damping of transients, reactive power, fault ride-through and fault-clearing capabilities, and adaptable response to primary and secondary frequency control

- Cost-benefit analysis of distribution digitalisation technologies for the reduction of technical losses. Funding: ENEL Iberia. The objective of this project is to evaluate the techno-economic impact of different digitalisation technologies on the distribution network technical losses. The evaluated technologies are OLTCs, capacitor banks, STATCOMs for reactive power support and unbalance reduction, DC links and battery energy storage systems

- PASTORA. Preventive Analysis of Smart Grids with Real-Time Operation and Renewable Assets Integration. Funding: Spanish CDTI. This project develops algorithms for the control and optimisation of the low voltage distribution grid by means of a state estimator especially suited for this application. This information allows improving the maintenance of critical assets like MV/LV power transformers and their adequate operation to regulate the LV voltage by means of OLTCs

- STM. Technologies for optimising the participation of renewable power plants in the ancillary service markets. The main objective of this project is to develop and demonstrate the technical viability of a management system which facilitates the participation of renewable power plants on ancillary service markets

- Hybrid-LV. Efficient Low Voltage Distribution by means of hybrid AC/DC networks. Funding: Spanish Ministry of Economy and Competitiveness. The project proposes a new concept of hybrid and efficient AC/DC networks to address the connection requirements of massive DC loads (electrical vehicle, photovoltaic generation and energy storage systems) emerged from the social need of achieving a decarbonised power system

## Partnerships

During 2018-2019 the following partnerships have been established during the development of research activities:

- Red Eléctrica Española (REE): Spanish Transmission Systems Operator (TSO). (www.ree.es)

- Endesa: Spanish distribution company integrated within the Enel Group. Endesa is the owner of the distribution network of SmartCity Málaga. (www.endesa.com)

- Ingelectus: Spin-off of the University of Seville specialised in innovative technological solutions to face the challenges that rise in the electrical grid of the 21st century. (www.ingelectus.com)

- Isotrol: Spanish company specialised in developing supervision and control tools for renewable energies, electricity distribution and electricity markets. (www.isotrol.com)

# DNV GL Developing New Testing Procedures

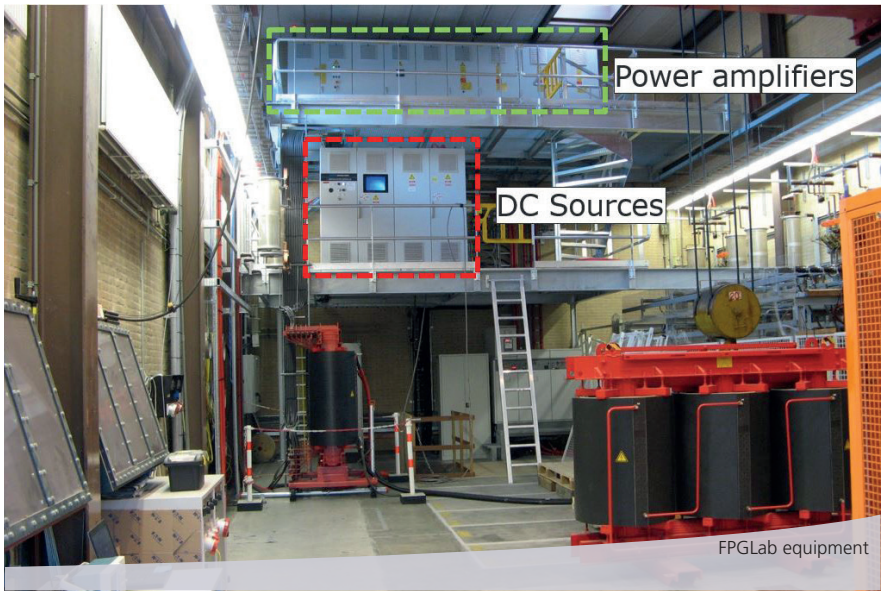
- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

**DNV GL** provides classification and technical assurance along with software and independent expert advisory services in the fields of onshore and offshore wind power, solar, conventional generation, transmission and distribution, smart grids, and sustainable energy use, as well as energy markets and regulations. One of DNV GL's facility highlights is the Flex Power Grid Laboratory (FPGLab), which focuses on DER and RES integration for smart grids and power electronics development.

**infrastructure.der-lab.net/dnv-gl**

In 2019 the Flex Power Grid Lab added the following DC power supply configurations capable of bi-directional operation:

- High-power (1.32 MW), HV (2kV):
  - equipped with Solar Simulator to operate as PV-Emulator
  - equipped with Battery Simulator to operate as Battery Storage (ESS)-Emulator
- High-power (200kVA), LV:
  - multiple (at least 6) configurations supported up to 750 V that can be driven by a real-time simulator (SFP link) and as PV or ESS emulators
- Co-simulation - Power Wind Turbine test bench



FPGLab equipment

## Consulting services

DNV GL unites the strengths of DNV, KEMA, Garrad Hassan, and GL Renewables Certification. DNV GL's 2,500 energy experts support customers around the globe in delivering a safe, reliable, efficient, and sustainable energy supply. DNV GL delivers world-renowned testing, certification and advisory services to the energy value chain, including renewables and energy efficiency. Their expertise spans onshore and offshore wind power, solar, conventional generation, transmission and distribution, smart grids, and sustainable energy use, as well as energy markets and regulations. DNV GL's testing, certification and advisory services are delivered independently from one another.

As of 1 January 2020, KEMA Laboratories (including the Flex Power Grid Lab) are part of CESI, a world-leading consulting, testing and engineering company in the field of technology and innovation for the electric power sector.

### New capabilities in 2020

- Test capability for Pulse Electric Acoustic (PEA) charge measurements in HVDC cables
- Test capability for DC breaker and DC GIS

### Simulation/optimisation tools:

- Power Factory
- PS-CAD
- AT-EMTP
- MATLAB-Simulink
- NI-LabView

### Research activities

DNV GL, in cooperation with wind turbine manufacturer Ming Yang, successfully tested the black start capability of a 1 MW wind turbine converter in the newly developed Cosimulation - Power Wind Turbine test bench in DNV GL's Flex Power Grid Laboratory in Arnhem, Netherlands. This research project is part of the European funded project Progress On Meshed Offshore HVDC Transmission Networks (PROMOTioN).

Black start capability test wind turbine converter

# INESC TEC Extending DER Integration Studies

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

INESCTEC
ASSOCIATE LABORATORY PORTUGAL

The Institute for Systems and Computer Engineering, Technology and Science (**INESC TEC**) is a private non-profit institution having as associates the University of Porto, INESC and the Polytechnic Institute of Porto. The institute was created to act as an interface between the academic world, the world of industry and services and the public administration in information technologies, telecommunications and electronics (ITT&E).

**infrastructure.der-lab.net/inesc_tec**

In 2018-2019 INESC TEC upgraded their capabilities with a precision power analyser and expanded their PHIL capacities by increasing the capacity in real-time simulation threefold. Furthermore, the research team acquired new design and simulation tools (PCB design, 3D modelling, multi-domain simulation of power electronics (PLECS)), which represent a substantial improvement in the development and testing capabilities of in-house prototypes. These are suited for studies related to DER integration, such as in-house development of electronic power converters for PV, energy storage (including hybrid inverters), in-house development of smart home products (appliances, energy metering and management devices, multi-variable sensors).

## New capabilities in 2020

- Expansion of the PHIL capabilities, with the acquisition of an additional and more powerful power amplifier
- Acquisition of an EMI testbed and a Controlled Climate testbed for electronic equipment (temperature and humidity), to further improve laboratory capabilities in the in-house development of electronic power converters suited for DER systems
- Acquisition of a fast charging station for the investigation of its impact and new solutions related to the integration of such devices in the network
- Creation of a test infrastructure for cybersecurity algorithms in the smart grids context

Prototype of a Home Energy Management System, developed in-house in the scope of the InteGrid project

## Consulting services

The INESC TEC infrastructure is prepared to perform in-depth power quality tests according to IEC 61000-3-2 and EN 50160 in electrical and electronics equipment and systems, such as commercial equipment or advanced/complex prototypes with non-conventional waveforms.

INESC TEC also offers testing storage systems regarding charging/discharging and thermal cycles, efficiency and thermography).

## Accomplishments

Scientific publications in several conferences (PSCC 2018, SEST 2019, Power Tech 2019) and journals, such as "IET - Renewable Power Generation".

The INESC TEC research team is active in a number of H2020 projects, such as InterConnect, coordinated by INESC and POCYT.

## Research activities

The following laboratory activities were carried out during 2018-2019:

- Extensive testing of network applications and prototypes developed under the H2020 European project SENSIBLE (in collaboration with EDP and SIEMENS). The tests conducted at INESC TEC included the implementation of a laboratory-scale LV network (0,4 kV), composed of LV cable simulators, loads and DER connected to both commercial converters and prototypes developed in the lab

- Development of hardware and software solutions for energy generation, management and optimisation at domestic level (hybrid electronic power converters suited to integrate PV and energy storage, and home energy management systems - HEMS), under the H2020 European project InteGrid

- Development of sensor prototypes (suited to measure CO2 concentration, irradiance, temperature, etc.) in the scope of energy management in buildings under the FEEdBACk European project

- PHIL testing of developed in-house power electronic prototypes for DER systems, optimisation tools for grid operation and others (load modelling validation, optimal motor starting, etc.) in the scope of several projects and other collaborations (H2020 European project SENSIBLE, ERA-NET project SMARES, FCT – ERA-NET project RESTABLE, EPFL)

## Partnerships

The activities developed in the laboratory were also performed in collaboration with industrial and academic partners.

Industry partnerships with:

- GP Tech
- EDP
- WithUs
- VPS
- SONAE
- IKEA
- Navigator

Academic Institutions:

- University of Porto/Faculty of Engineering (FEUP)
- École Polytechnique fédérale de Lausane (EPFL)

Prototype of a residential hybrid inverter that accommodates PV generation and energy storage developed in the course of the InteGrid project

# Full-Scale Grid Integration at University of Luxembourg

- Microgrids & Distribution Network
- PV Systems
- Storage Systems
- Smart Buildings
- HIL / Co-simulation

The NetPower DemoLab of the University of Luxembourg carries out experimental verification of RTD works towards full-scale accommodation of solar derived power generation at all voltage levels of the grid for Luxembourg's utility CREOS.

The NetPower DemoLab's structure in the computer-aided engineering process is combining real and virtual testbeds progressing from offline to online testing. For the full-scale PV integration analysis, a virtual topology of modified CREOS network with meshing capabilities is implemented in the lab.

The NetPower DemoLab equipment covers real-time software simulation backed up by fast FPGA-signal processing hardware, extended to real-physics electrical power in the 100kVA range.

### New capabilities in 2020

PLC based smart metering network and a hardware model of the modified CREOS virtual network are planned to be implemented in 2020 to further extend the capabilities of the lab.

The smart metering network will provide technical means for SCADA system security and reliability testing and research on communication influence on grid control and PV integration.

The grid hardware model backed up by fast FPGA signal processing hardware will advance HIL simulations and boost the research on PV and battery integration into the grid.

### Consulting services

NetPower DemoLab offers consulting services on power system modelling, PV and battery grid integration, grid reconfiguration, hosting capacity calculation and testing of inverter control algorithms on NI FPGA-based inverters.

UNIVERSITÉ DU LUXEMBOURG

The NetPower DemoLab of the **University of Luxembourg** carries out experimental verification of RTD works towards full-scale accommodation of solar derived power generation at all voltage levels of the grid for Luxembourg's utility CREOS. Supported by FNR, as a national cooperation platform for the University's Electrical Engineering Institute, its Interdisciplinary Centre SNT and its CSC Research Unit, it broadens to the national RTD centre LIST.

**infrastructure.der-lab.net/**
**uni_luxembourg**

NetPower DemoLab

## Accomplishments

The NetPower DemoLab team summarised the grid reconfiguration analysis study in a paper titled "Increasing DG integration level by network configuration subset analysis", which was presented at the SEST 2019 conference.

Prof. Sachau of the University of Luxembourg is currently working on electrical energy security as a visiting research fellow at the European Commission´s Joint Research Center in Ispra, addressing distributed balancing towards EU full supply by renewable energies.

## Research activities

Currently, the research in the lab is focused on hosting capacity (HC) improvement by grid reconfiguration and grid code improvement in a medium voltage grid with meshing possibilities.

The study is performed on a 43-bus 20 kV MV network model representative of Luxembourg's grid. The modelling, reconfiguration, HC calculation and analysis are done using Pandapower software. To assess the cross-influence of DGs and the influence of DG location, four PV plants connected at different parts of the grid are considered.

Furthermore, several PV control case scenarios are taken into account to assess the impact of grid code modification on the HC of the grid. Additionally, the study offers a summary of grid reconfiguration, which provides the grid operators possibility to safely reconfigure the system while keeping the HC within a certain range.

The results have shown that grid reconfiguration analysis should be the first consideration in HC improvement for the grid operators since it can increase the HC by up to four times compared to the worst cases and does not require any additional expensive grid reinforcement. Grid code improvements via curtailment or inverter oversizing proved to increase the hosting capacity of the system by up to 15% and utilise the grid closer to the designed limits.

## Partnerships

From October 2019 on, Prof. Sachau is seconded to JRC Ispra contributing to the field of EU electrical energy security.

NetPower DemoLab

# New Multi-Energy Facility at HES-SO

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

Hes·so VALAIS WALLIS
Haute Ecole Spécialisée de Suisse occidentale
Fachhochschule Westschweiz
University of Applied Sciences Western Switzerland

The Institute of Systems Engineering is part of the University of Applied Sciences and Arts Western Switzerland Valais (**HES-SO** Valais-Wallis). Both aim at collaboration between economy, industry, higher education and politics and the development of new energy-related services and products. The key activities of the institute focus on energy, particularly renewable energy and smart grids, and the development of instruments for support in the field of energy, health and environment.

**infrastructure.der-lab.net/hes-so**

In 2018-2019 the HES-SO research team performed the following activities:

- Deployment of a full-scale demonstration and testing 700V DC microgrid, with PV generation (20 kW), battery storage, EV charger and Energy Management System (EMS), working either in islanding or in grid-connected mode
- In collaboration with the International Association UTOPIA, demonstration and testing of an AC microgrid comprising two experimental living modules with local PV generation, battery storage and energy management
- Design of adaptive protection solutions for active distribution networks
- Deployment of an integrated laboratory-wide ICT infrastructure for monitoring and control, based on the cloud.IO IoT framework
- Development of a new modular converter prototyping system and testing framework for converters and controllers based on the Typhoon HIL 402

### New capabilities in 2020

The HES-SO research team will set in operation Energypolis - a new academic campus that will be used as a full-scale multi-energy laboratory with local renewable energy production (400 kW peak of solar photovoltaic panels), electrical AC and DC microgrids, thermal low temperature CO2-based microgrid, bidirectional power-to-gas facility connected to the local gas network and changeable set of energy converters. Energy conversion appliances as well as energy management strategies can be tested at Energypolis.

Furthermore, HES-SO will conduct the following upgrades:

- Set-up of a test bench for Energy Management Systems (EMS) based on HIL signal and power technologies (Imperix / Opal-RT)
- The testing facilities for power converters and drives up to 50 kVA will be upgraded for new grid interconnection standards compliance including EMC. A Full Anechoic Room equipped with power inlets will be available for radiated emissions testing

Energypolis

### Consulting services

- Power quality & EMC expertise on site (i.e. impact of harmonics, EMI Power Line Communication (PLC), earth leakage currents)

- Pilot design and operation for "Building to grids" digital services to turn existing buildings into active elements of energy grids and markets

### Accomplishments

- Launch of the new Institute of Sustainable Energy, an interdisciplinary research entity addressing technical, business and sociological aspects of the energy transition.

- Best paper award at the 3rd IEEE International Conference on DC Microgrids 2019 for the paper "Power electronics for a LVDC-microgrid with local PV production and electrolytic converter"

- In collaboration with the local utility Energie Sion Région (ESR), successful operation of a demonstrator managing the flexibility of more than 200 buildings and industries (H2020 project GOFLEX demonstrator)

# TUAS Building up PV Research and PHIL Infrastructures

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

TURKU AMK
TURKU UNIVERSITY OF APPLIED SCIENCES

The **Turku University of Applied Sciences (TUAS)** provides education in the domains of renewable energy production, distributed energy systems, energy storage, power electronics and smart grids, in cooperation with their New Energy Research Center. The facility is equipped with a photovoltaic SOLAR Lab and a distributed energy system DES Lab. The main competences are photovoltaics, wind energy, electrochemical energy storage, power electronics, measuring techniques as well as data management.

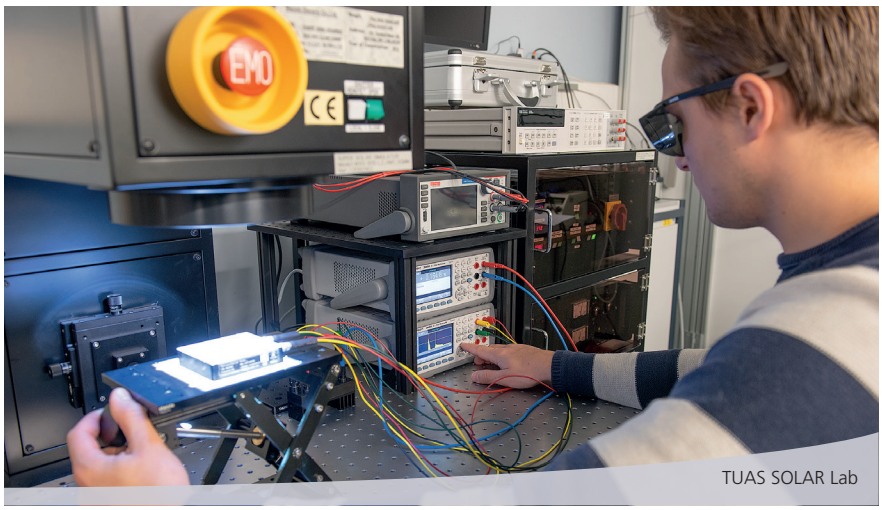
**infrastructure.der-lab.net/tuas**

In 2018-2019 the TUAS research team performed the following upgrades:

- In addition to the class AAA PV module flasher and steady state cell Super Solar Simulator, the TUAS SOLAR Lab is now equipped with a Mechanical Load Tester for PV modules, a 8"x 8" class AAA cell flasher and a fast 200-1700 nm spectroradiometer
- The LVDC downscale Microgrid is completed with a 50 kVA Grid Simulator amplifier and different PV and battery emulators. With the Imperix Fast converter prototyping system, the TUAS team can emulate any converter topology including programmable controller up to 15 kVA
- The cybersecurity laboratory of TUAS extended its services for manufacturing industry and companies developing IoT products or services

## New capabilities in 2020

- The SOLAR Lab will acquire a mobile PV Module Lab for comprehensive module testing in the field conditions. The Mobile Lab is equipped with a class AAA LED solar simulator and a high resolution electroluminescence imaging system
- A Real Time Simulator will complete the DES Lab allowing PHIL and CHIL research and testing activities in the fields of energy management, converters, grid compliance and power quality
- Fast charging/discharging of EV batteries will become possible with high DC bidirectional power supplies, enabling studies on grid impact of fast charging stations for the distribution grid and e-Mobility



TUAS SOLAR Lab

## Consulting services

- PV modules and cells testing (indoor, outdoor, on-site)
- PV plant commissioning testing
- Converter testing (efficiency, standard pre-compliance for PV converters and EV battery chargers < 50 kVA)
- Distributed energy systems concept development (buildings and districts): sizing, layout, components specification, control strategies, storage integration
- Power quality analysis, clean-up actions and analysis for power line communication in smart metering applications
- Cyber-security testing of equipment and services

## Accomplishments

- Launch of the New Energy Research Center at TUAS
- Setting up a photovoltaic test laboratory, unique in Finland
- Functional downscale Energy hub emulator based on LVDC microgrid, including emulation of EV charging, PV production and active front end interface to the grid

## Research activities

In the Smart Electric Bus Charging Station Integration (SeBNet) project TUAS has made Impact Studies of eBus quick charging to the distribution grid, based on future scenarios, charging station and distribution grid modelling. This will help DSOs to plan a future charging station network.

In the SeBNet project, TUAS has also developed a new charging station hub concept and prototype. This prototype integrates local battery energy storage, PV generation, LV DC distribution bus and energy management system. The prototype enables development and testing of different energy management strategies.

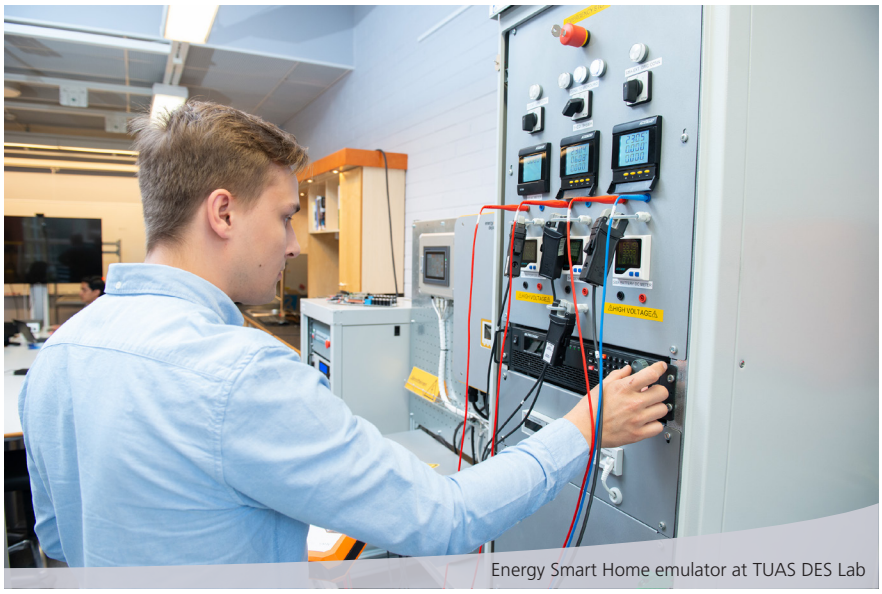
## Partnerships

- Collaboration with Sandia National Labs (US) on bi-facial PV research in Nordic high latitude conditions
- Collaboration with HES-SO on LVDC microgrid, distributed energy storage and EV-charging hub testing
- A strategic partnership with LUT University Energy Market and solar energy economy group
- NERC at TUAS is a new member of the DERlab association

## Publications

[1] EU PVSEC 2019 Paper with Sandia National Laboratories et.al. : "Self-consumption rate achieved by the bifacial east-west vertical PV system compared to the conventional south facing system in Nordic conditions". Samuli Ranta, Joshua S. Stein, Hugo Huerta, Aleksi Heinonen, Erin Whitney.

[2] IEA PVPS 2018 Best Practice Report with Sandia National Laboratories et.al. : "Review on Infrared and Electroluminescence Imaging for PV Field Applications". K.A. Berger, R.H. French, M. Herz, U. Jahn, M. Köntges, M. Paggi, D. Parlevliet, S. Ranta, M. Richter, J.S. Stein, T. Tanahashi, I. Tsanakas.



Energy Smart Home emulator at TUAS DES Lab

# TU Sofia Extending Laboratory Capabilities

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

The Technical University of Sofia (**TU Sofia**) educates specialists in topics essential for the industrial development: mechanical and electrical engineering, electronics, power generation, transport, automation, computer science and telecommunications, textile engineering, industrial management. The **Research and Development Sector (RDS)** of TU Sofia deals with the organisation, administration and services of the research activities under contract with national research programmes and industry.

**infrastructure.der-lab.net/tu_sofia**

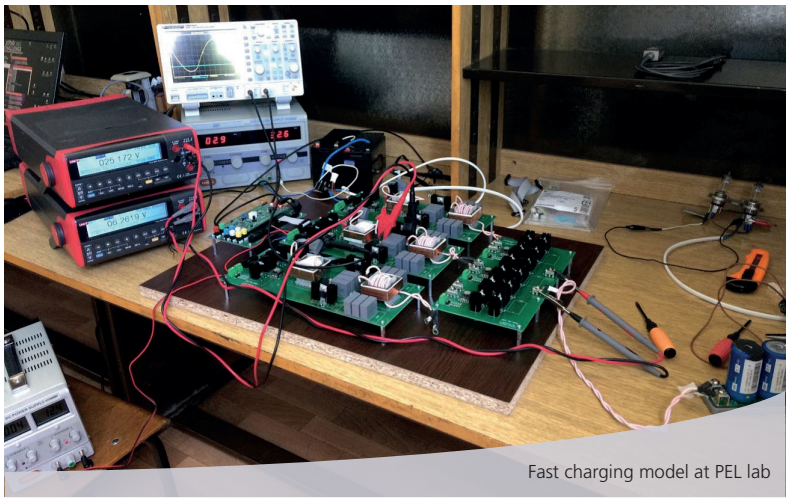
The Power System Stability Laboratory (PSSL), Power Electronics Laboratory (PEL) and Communications, Process Control and Energy Efficiency in Industry Laboratory (CPCEEIL) of TU Sofia gained the following upgrades in 2018-2019:

- Physical model for micro-, mini- and nanogrid research and testing
- Physical model of a synchronous generator based power unit with extended grid support functions
- Programmable DER unit with enhanced grid support functions and synthetic inertia
- Physical PV generator emulator
- Fast charging model of EV

### New capabilities in 2020

In 2020 the laboratories plan to develop:

- Control systems for smart buildings
- Physical model of a smart load controller for grid supporting dynamic electricity markets
- Physical model of an EV charging and grid feeding controller for grid supporting dynamic electricity markets



Fast charging model at PEL lab

### Consulting services

- Voltage, angular and frequency stability analysis
- Analytical and physical modelling of electrical power systems
- Power electronics converters with improved power factor
- Power systems dynamics
- EV wired and wireless charging systems
- Autonomous, micro- and minigrids
- Power generation prediction of DER
- Energy and power management systems
- Intelligent power system automation and control
- Modelling and simulation of smart grid systems and components
- Model, SIL and HIL experiments
- SCADA systems of distribution, microgrids and industry
- Energy storage systems

Communication in power systems

## Research activities

A research on Micro- and Nano grid Power System Stability Support Capabilities under Major Power System Disturbances has been developed.

PSSL carried out research on Micro- and Nanogrid Power System Stability Support Capabilities under Major Power System Disturbances.

CPCEEIL plans to test different algorithms for optimal energy flow in a small HIL system, which consists of a PV model, EV models, real loads and real control system with interoperability functionality with the electricity market systems. Also, CPCEEIL will obtain new software and real control systems for smart buildings and will implement them for testing of systems for planning and control of DER under limitation of the grid system. The results of this work can be used for planning of the allocation and size of storage systems, PV production and loads allocation.

PEL performs modelling, investigation and design of modular topologies for EV fast charging based on resonant DC-DC converters with voltage clamping applied to a part of the capacitor in the series-resonant tank operating above the resonant frequency. PEL also performed a study of a controllable three-phase rectifier with LC output filter stage. Using a proper control algorithm with sinusoidal PWM, power factor correction is realised. A mathematical model of the existing control algorithm is developed in MATLAB for examination of its operability and specificities.

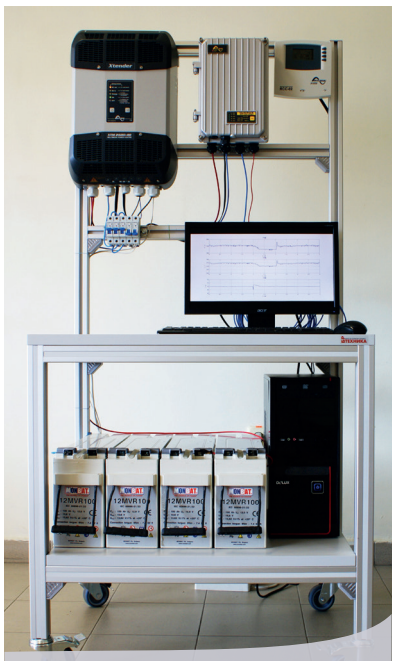
## Partnerships

New partnerships within the H2020 PANTERA project and SIRFN have been established. The partnerships with the Bulgarian TSOs and DSOs regarding power system analysis have been further developed.

PSSL elaborated partnerships with Bulgarian TSOs and DSOs regarding power system analysis. CPCEEIL collaborates with Siemens Industrial Automation, Siemens Building Automation and Mitsubishi Control Systems. PEL's main partnerships are with major power electronics manufacturers in Bulgaria.

## Publications

Optimised power flow control of smart grids with electric vehicles and DER. Metody Georgiev, Rad Stanev, Anastassia Krusteva, June 2019. DOI: 10.1109/ELMA.2019.8771575. Conference: 2019 16th Conference on Electrical Machines, Drives and Power Systems (ELMA).



PSS lab's physical model for micro-, mini-, and nanogrid research and testing

# MicroDERlab Improving DC and Hybrid Microgrid Infrastructure

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Fuel Cell Systems
- Storage Systems
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

MicroDERLab

**MicroDERLab** is a Research Group at Politehnica University of Bucharest (UPB) in Romania, reuniting teams from the Faculty of Electrical Engineering and the Faculty of Power Engineering. MicroDERLab promotes a common research agenda on electrical engineering topics focusing measurements and instrumentation for a faster deploying of the intelligent networks of the future. MicroDERLab has a strong record of R&D projects in DC microgrids area.

**infrastructure.der-lab.net/ microderlab**

In 2018-2019 MicroDERLab gained the following upgrades:

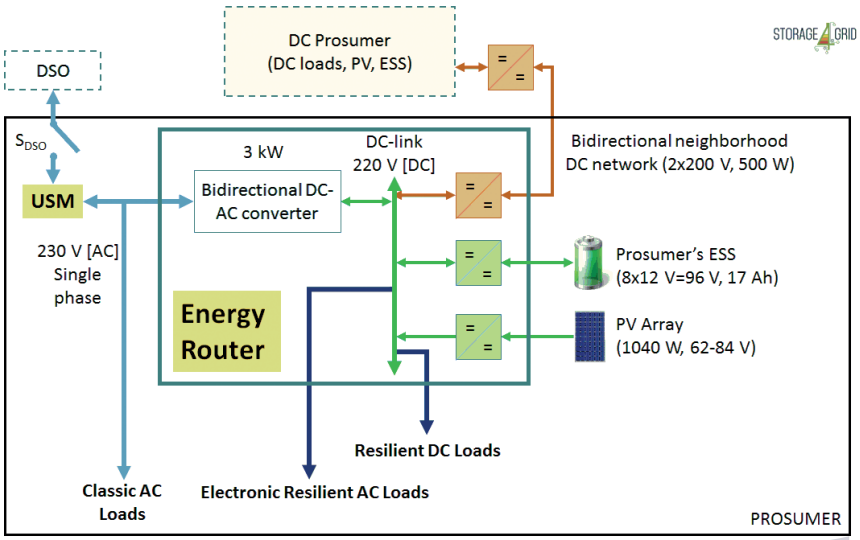
- The Energy Router: a 3kW static converter/modular platform enabling controlled energy transfer from AC sources to AC loads and to a DC section (a control interface to electric storage, DC loads and PV generation). An important feature is the accessibility of the DC bus that operates unipolar up to 300V and enables controlled bidirectional energy transfer
- Smart Metering Pilot site at UPB's student dorms consisting of state-of-the-art electricity smart meters with extension modules enabling high reporting rate (up to 1s) and data transfer to derive high resolution load curves for energy communities

## New capabilities in 2020

- Improvement of the storage and power converters interface models for DC and hybrid microgrids, including SOC estimation, control of the access time to power and optimal planning/operation for prosumers (PV and storage) as part of energy communities with DC link
- Deriving a set of load curves based on high reporting rate measurements over a period of one year for prosumers (commercial and residential) and for microgrid electrical infrastructures

## Consulting services

The newest service provided by the MicroDERLab team is the development of high resolution models for storage, PV and loads to solve optimisation problems regarding energy efficient restructuring of energy intensive business.




MicroDERLab's Energy Router

## Research activities

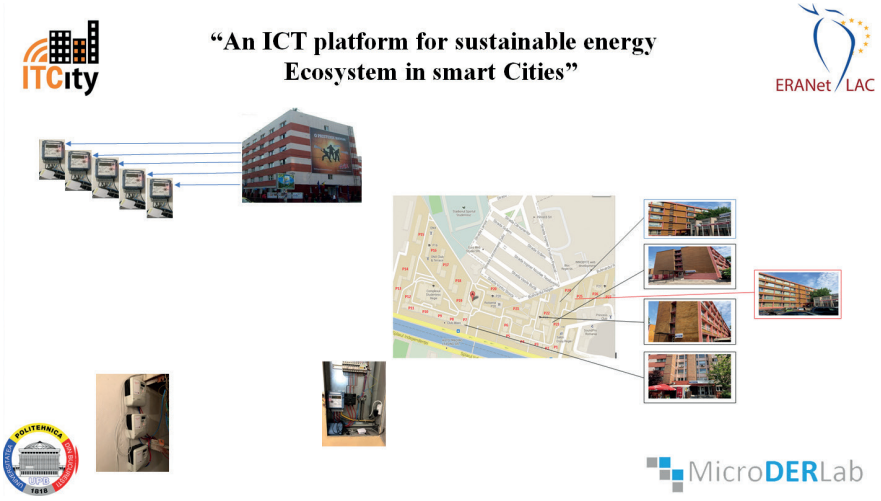
Identification of fault sources and limits of stability of the grid using PMUs connected to the TSO main bus-bars (400kV) were studied as part of an H2020 project. Team members have contributed to grid codes (ENTSO-E) and WAMCS /WAMPAC solutions based on synchronised measurements.

## Partnerships

In the last years, the UPB-MicroDERLab team successfully collaborated with institutes and universities in Europe (continuing long term collaborations with RWTH Aachen and KIOS Research Center), Latin America (Chile and Brazil as part of ERA-NET LAC project ITCity) and the United States of America (Keysight Technologies, Colorado State University). The International Microgrid Symposium was organised in 2018 at UPB bringing experts together from around the world.

## Publications

Toma, L., Sanduleac, M., Baltac, S.A., Arrigo, F., Mazza, A., Bompard, E., Musa, A., Monti, A., "On the virtual inertia provision by BESS in low inertia power systems", 2018 IEEE International Energy Conference, ENERGYCON 2018, 27 June 2018, Pages 1-6.




MicroDERLab's Regie Pilot

# Uni Manchester Developing HV, RTDS and Power Conversion Labs

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Fuel Cell Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

MANCHESTER 1824

The University of Manchester

The Electrical Energy and Power Systems (EEPS) and Power Conversion (PC) groups at the School of Electrical and Electronic Engineering of the **University of Manchester** are at the forefront of research and teaching in the field of electric power engineering. Particular areas of competency of the research groups include transformer insulation and monitoring, polymeric insulation, power system transients, design and operation of power system plants, transmission networks, and smart low-carbon distribution networks.

**infrastructure.der-lab.net/uni_manchester**

In 2018-2019 the University of Manchester enhanced the following facilities for HV testing:

- 800 kV AC test set
- Advanced digital measurement equipment

Furthermore, a number of projects and research were performed involving the following infrastructure capabilities:

- Assessment of new tower, conductor and cable designs
- Electromagnetic field and interference studies
- Earthing analysis
- Failure mode analysis using FEA methods (electrical, mechanical and multi-stress)
- Noise and corona analysis
- Insulation system design, development and testing
- Non-conventional testing of aged assets
- Condition monitoring of HV plants
- New materials and applications
- Forensic analysis
- Asset management
- Long-term testing
- Design of offsite test setups for HV plants

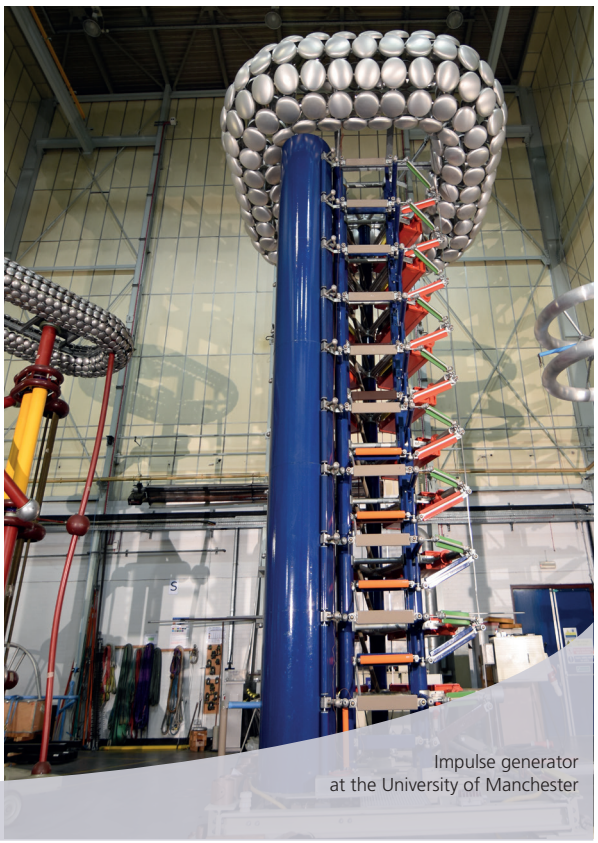
## New capabilities in 2020

In 2020 new HV equipment will be acquired as the laboratory is moved to the new Manchester Engineering Campus (MECD) building.

MECD will be the single largest home for engineering in any UK university. The campus will contain a huge variety of adaptable workspaces to support the leading research of the University of Manchester. Basement areas will be devoted to heavy duty and vibration isolation laboratories and HV facilities, which will be on full public view behind floor-to-ceiling windows.

## Consulting services

The University of Manchester offers a wide range of consulting services, particularly for electricity companies (e.g., National Grid and Electricity North West), from desk based simulations to laboratory and site tests, in line with their facilities and research interests.



Impulse generator at the University of Manchester

## Research activities

Desk based analysis

- Assessment of new tower, conductor and cable designs
- Electromagnetic field and interference studies
- Earthing Analysis
- Failure mode analysis using FEA methods (Electrical, Mechanical and Multi Stress)

Lab testing

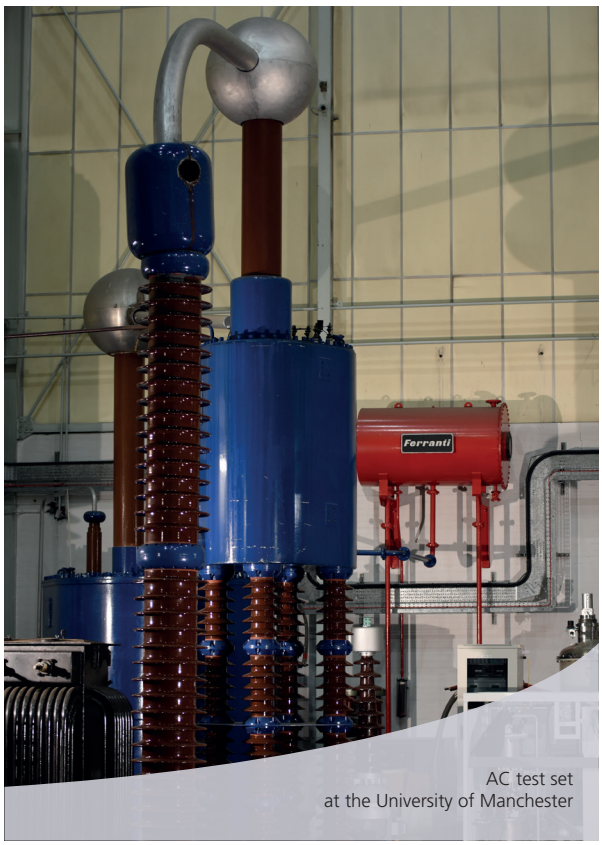
- Noise and corona analysis
- Insulation system design, development and testing
- Non-conventional testing of aged assets
- Condition monitoring of high voltage plant
- New materials and applications
- Forensic analysis

Site testing

- Asset Management Techniques
- Long term testing
- Design of offsite test set up for high voltage plant

## Partnerships

Several partnerships with different research and industrial partners are constantly established through collaboration in different research projects. Currently, the university collaborates with several DERlab members (e.g., The University of Strathclyde, Fraunhofer, and so forth), as well as with other research and industrial partners (ENWL, Scottish Power Energy Networks and Schneider Electric, Alstom, among others) as part of several European and UK projects.




AC test set
at the University of Manchester

# EDF R&D Extends Concept Grid

- Microgrids & Distribution Network
- Power Electronics
- PV Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation

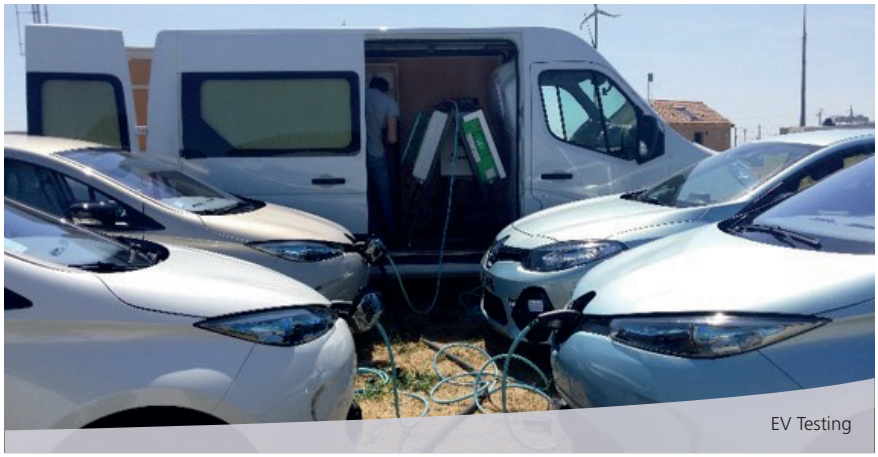
Main objectives of **EDF**'s R&D are fostering innovations, cutting CO2 emissions by developing alternatives to fossil fuels, and building safer power grids. EDF implements a proactive policy of partnership and exchange with clients and laboratories in France, Europe, and all over the world. The research and development branch of EDF contributes to the performance of the operational crews of EDF and aims to identify and prepare levers for growth in the medium to long term.

**infrastructure.der-lab.net/edf**

In 2019 Concept Grid put into service a brand new platform for testing ultra-fast charging terminals for EVs. This network extension required the installation of additional substations with a power capability of 1.6MW, looped on the existing MV network. This platform has a concrete slab of more than 160m² and allows testing of various EV terminal manufacturers in a real network environment combined with storage system and PV productions. In addition, Concept Grid newly installed a 2.3MW Li-ion battery system as part of H2020 EU-SYSFLEX project with the target to test multi-services provision to the power system.

## New capabilities in 2020

EDF has the ambition to become a key player in the hydrogen sector in France and around the world. In 2020, EDF R&D will create a new platform dedicated to testing hydrogen electrolyser solutions that will be directly connected to the MV network of Concept Grid. The platform will allow to characterise the performance of electrolysers and evaluate their abilities to provide grid services combined with renewable energy and storage technologies.



EV Testing

## Consulting services

Concept Grid's mission is to boost development and de-risk solutions. If any doubt subsists regarding a new technology, Concept Grid is the tool to challenge it and get a clear vision on its effectiveness.

Concept Grid is open to long-time collaboration as well as "one-shot testing". DSOs, manufacturers, universities, researchers are welcome to test their devices and solutions in real conditions with EDF Concept Grid, which would be impossible to fully test in the field.

## Accomplishments

In 2018, EPRI presented the Concept Grid team with the PDU Technology Transfer Award for the application of Development of Microgrid Assessment Methodology and Microgrid Control Technologies.

## Research activities

A proof of concept has been performed at Concept Grid to demonstrate a technical solution to smooth strong short term fluctuations of the power output of a PV farm using a flywheel storage system (100kW).

A real network configuration has been set up in order to be able to illustrate these scenarios. With a proper control developed by EDF R&D, the ESS can manage the power at the point of common coupling achieving SoC management. This kind of control can allow to facilitate the integration of PV generation by limiting its impact on grid frequency stability, especially on small islands that are more likely to suffer grid stability issues.

Additional grid services have been performed with a flywheel and a super capacity storage system such as renewable peak shaving, frequency control on island grid, etc.


Concept Grid


UFC Platform

# Smart RUE of ICCS-NTUA Advancing Smart Grid Research

- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- PV Systems
- Wind Systems
- Biomass / CHP Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

The research and development activities of the **Institute of Communications and Computer Systems (ICCS)** of the National Technical University of Athens (NTUA) evolve around different aspects of telecommunications, computer systems and techniques and their application in a variety of areas. Among the research groups of ICCS are the Electric Energy Systems Laboratory (EESL), which offers experimental training for students, and Smart RUE, which focuses on smart grid research.

**infrastructure.der-lab.net/iccs**

## Dynamic inductive EV charging

Smart RUE developed a dynamic inductive charging system that considers the wireless transfer of energy while an EV moves over the charging station. It comprises a magnetic coupler, compensation capacitors and the DC/AC converter that provides the required high frequency current to the charger. The implemented control scheme can significantly increase the efficiency of the system, while maximising the energy transferred to the vehicle when it moves over the station. A relevant laboratory model has been set up.

## Anti-islanding testing

Based on the IEEE 1547.1 standard, the Smart RUE team developed a laboratory setup for performing anti-islanding tests for both AC and DC systems. Performing PHIL tests, the researchers accomplish convenient and accurate detection in real-time simulation.

## Simulation software of electric railway systems

Smart RUE designed an electric railway systems software tool that simulates the operation of railway systems, aiming towards the optimisation of their performance. The tool can model all kinds of railway electrical systems and main components such as rectifiers, storage devices and inverters in case of energy injection back to the distribution system.

## New capabilities in 2020

- Upgrade of the real-time simulator
- PHIL setup for railway systems focusing on the integration of storage devices for regenerative energy management
- Testing the operation of non-interconnected islands with a very high penetration of RES in a CHIL/PHIL environment for ancillary services and protection studies

ERIGrid Summer School "Advanced operation and control of active distribution networks" at NTUA

## Consulting services

ICCS-NTUA supports the Greek DSO - HEDNO - in several areas related to the integration of DER and smart grids such as: planning and operation of non-interconnected islands, improving the observability and active management of the distribution network, power quality analysis, and impact assessment of EV integration.

## Accomplishments

- NTUA's Prof. Nikos Hatziargyriou was elected Chairperson of ETIP SNET (January 2018 - July 2019, currently vice-chair)
- IEEE PES "Prabha Kundur" award to Prof. Nikos Hatziargyriou for "contributions in the dynamic performance and control of power systems with dispersed energy resources"
- "Researcher of the Year" award to Dr. Ioannis Vlachos in the field of blockchain and their application in the energy sector, during the EventHorizon 2019 Summit
- 2018 IEEE PES Working Group Recognition Award to the report "Contribution to Bulk System Control and Stability by Distributed Energy Resources Connected at Distribution Network" led by Prof. Nikos Hatziargyriou
- Involvement in the Executive Board of the Wind Empowerment association through Kostas Latoufis and Athanasios Vasilakis

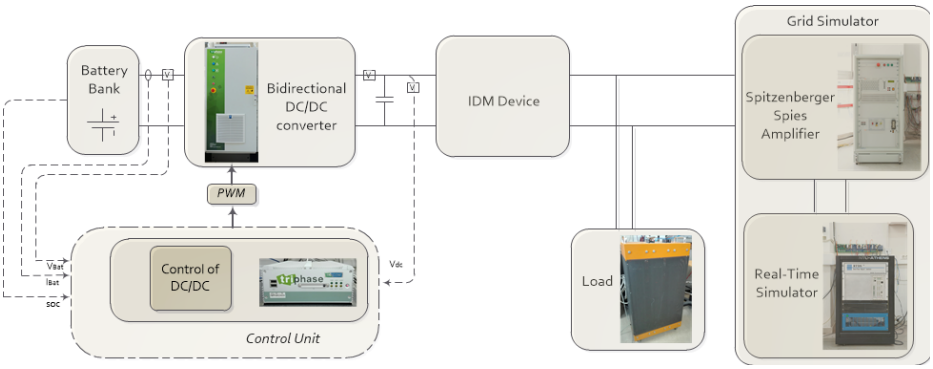
## Research activities

ICCS-NTUA is currently participating in nine research projects funded by the EC (WiseGRID, Shar-Q, GriDSOL, iDistributedPV, CROSSBOW, coordiNet, ERIGrid, Compile, TESTBED). It contributes to the development of tools for smart grid stakeholders and management platforms for EV and RES, while it also contributes to studies concerning the planning and operation of non-interconnected islands with a very high RES penetration, methods to increase the PV penetration in distribution networks, the coordination between the TSOs in the southeastern European region and the cooperation between TSOs and DSOs. Moreover, ICCS-NTUA contributes to advanced laboratory methods, such as hardware in the loop simulation, and promotes consumer engagement by supporting energy communities. Several of the aforementioned concepts and tools have been successfully deployed in pilot sites.

ICCS-NTUA develops, among other, innovative concepts for microgrids control, energy markets (centralised vs. decentralised), machine learning applications in power systems (e.g. load, RES forecast), railway systems and modern education methods. It performs numerous education and training activities for academia and industry, such as the "ERIGrid Summer School on advanced operation and control of active distribution networks" (June 2019), while it is actively involved in specific educational sessions on sustainability and environmentally friendly technologies for high schools. It organises workshops and performs research activities to promote and facilitate energy communities in Greece in close cooperation with citizens and municipalities. The Electric Energy Systems laboratory has hosted 16 researchers in the framework of seven Transnational Access projects of the ERIGrid project leading to two success stories and several publications. It also hosts international visitors from China (Hefei University), Italy (Marie Curie projects), etc. Moreover, it is involved in rural electrification projects in developing regions (Nepal, Ethiopia, etc.)

## Partnerships

- Cooperation with Electra Energy Cooperative to promote and support energy communities in Greece
- Cooperation with the DAFNI Network of Sustainable Greek Islands for the design and deployment of microgrids in Kythnos island
- ERIGrid Summer School in June 2019 in cooperation with HEDNO and RTDS
- Active participation in ETIP-SNET, DERlab, Wind Empowerment, IEEE. Task Forces, CIGRE and CIRED WGs, etc.



# New Energy Storage Capabilities at Lemcko

- Microgrids & Distribution Network
- Power Quality & EMC
- PV Systems
- Wind Systems
- Storage Systems
- E-Mobility
- Smart Buildings
- Education & Training

**Lemcko** is the Electrotechnical Research and Power Quality Facility of Ghent University. The facility offers consultancy and troubleshooting, courses and research on three main areas: power quality, distributed generation, and energy efficiency. One of Lemcko's main objectives is to facilitate the transition from innovative academic research to real-life integration of these innovations into the LV grid by using its expertise in low frequent power quality (<2kHz), general LV electrical installations, energy efficiency and

**infrastructure.der-lab.net/lemcko**

In 2018 the lab was expanded with a storage system, in which different battery technologies (10kWh each with a C-rate from 0.5 to 3), combined with supercap storage (2F) and a CHP emulator (50kVA) on a DC bus are connected. This setup was then connected to the distribution network with a DC/AC inverter (160kVA). The purpose of this emulator is to investigate what the dynamic possibilities of storage are and how different technologies can be linked to each other and operate in a stable way.

## New capabilities in 2020

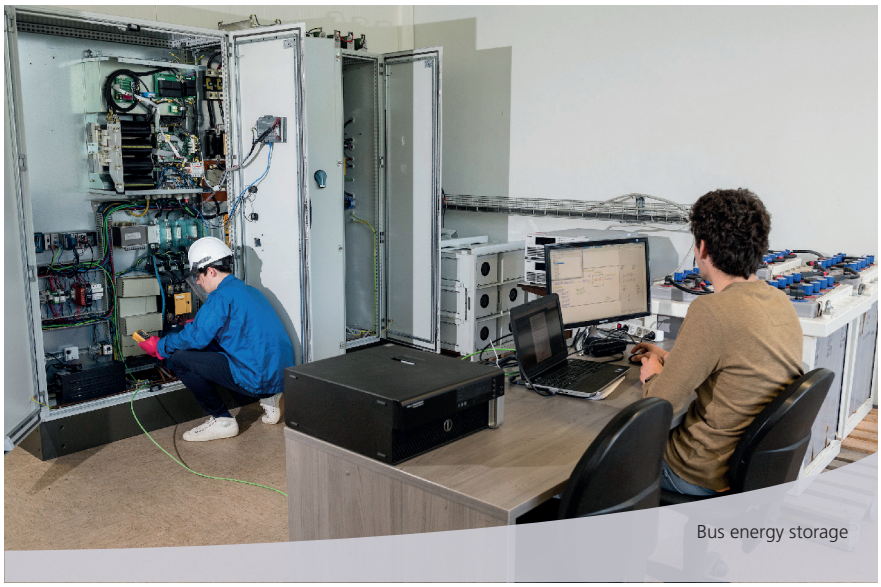
The plan is to expand the lab with different freely programmable 4Q AC/DC sources (resp. a PV, a wind and a V2G emulator) with the intention of building a DC backbone to link various renewable sources to Lemcko's existing DC storage system, consisting of different battery technologies and a supercap. This setup enables the Lemcko team to study the dynamic interaction between PV, wind, storage and V2G applications. This system will then be connected to the existing LV emulator through a unique DC/AC bus in order to analyse the impact of concentrated RES applications combined with different storage systems.

## Consulting services

- Feasibility studies for optimised combination of RES & Storage
- Analysis of aggregation levels for different kinds of end-users
- Optimisation of self-providing & self-consumption
- Analysis of the impact of time resolution of industrial loads combined with RES
- Predictive analytics

Power quality lab

© Gerald van Rafelghem



Bus energy storage

## Research activities

**In the domain of PV analyses:** Optimisation of the orientation of PV for obtaining an optimal self-sufficiency with a minimum storage capacity which is non-location based (i.e. independent of any specific consumption) and describes the flattening of the yield curve. Sizing algorithms are developed including optimisation of the storage operating conditions (DoD, LoC, C-rate, SoC, etc).

**Impact of time resolution on simulation models:** Analyses are performed to study the accuracy of the results when the time resolution of the input data (PV, wind and consumption) are based on 1 minute up to 15 minutes. Based on these results optimisation of storage and peak shaving can be analysed. This will form the base for further studies on predictive analytics and dynamic electricity prices

**Aggregation:** Aggregation of consumption profiles on different energy consumption levels, including the impact of RES sources has been investigated based on the influence of the level of aggregation and consumption profiles in a self-developed microgrid, i.e. via classifications of the individual users. It is shown that the aggregation level has a significant impact on the behaviour of the consumption profile, and microgrids composed of different individuals can exhibit very different behaviours. Based on these conclusions further research on aggregation techniques including storage will be performed to analyse the impact of both distributed RES and storage compared to decentralised systems.

Bus energy storage

# CVVOZE Strengthening Testing Infrastructure for Liquid & Solid Dielectrics

- High Voltage & High Power
- Power Electronics
- Power Quality & EMC

CVVOZE
Power Laboratories

**CVVOZEPowerLab** was founded as part of the Centre for Research and Utilisation of Renewable Energy (CVVOZE), a research establishment of the Faculty of Electrical Engineering and Communication at the Brno University of Technology. The research infrastructure consists of two strategic laboratories dealing with high current and high voltage.

**infrastructure.der-lab.net/cvvoze**

In 2018-2019 the CVVOZEPowerLab gained the following upgrades:

- Tettex Precision Oil and Solid Dielectric Analyser Type 2830/2831
- Test Cell for Liquid Insulating Materials Type 2903
- Test Cell for Solid Dielectrics Type 2914
- Haefely Hipotronics Water Cable Test Terminations and Water Processing Unit Type CTT 350
- Haefely Hipotronics SF6 Standard Capacitor, NK Series 3370, 50 pF, 300 kV, PD Level <3pC
- Increase of testing parameters in Switchgear Laboratory (25 kA/ 1750 V AC, 25 kA/ 1800 V DC)
- Second high-speed camera i-speed 726R (2048 x 1536 resolution, up to 1,000,000fps)
- New 3 sets for dynamic pressure measurement (6 available in total)
- 2 advanced spectrographs (up to 100,000 spectra per second, 4 grids for different sensitivity)
- Far-field microscope connectable to high speed videos (resolution below 1 µm)

CVVOZEPowerLab's HV research was focused on the measurement of changing electrical parameters and degradation levels in liquid and solid dielectrics. In addition to heat, the degradation effect was also monitored in intense ultraviolet radiation, high frequency electric field and DC electric field. The research results were publicised in a number of papers in international journals.

## Consulting services

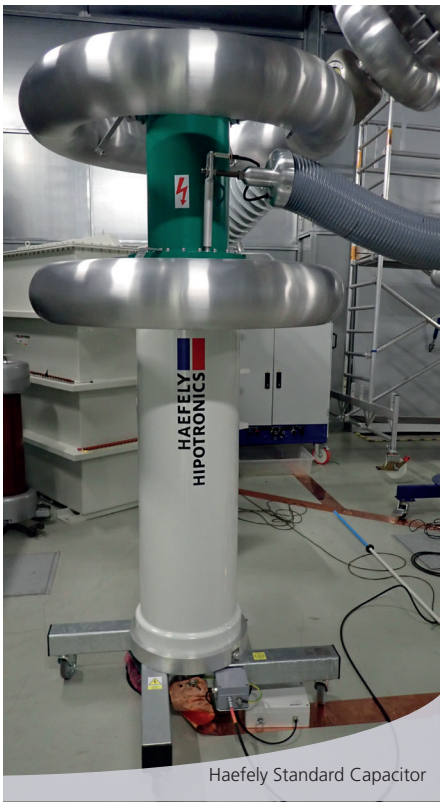
- Simulation of electromagnetic fields in power switching devices
- Simulation of temperature field distribution in power switching devices
- Calculation of radiative properties of plasma (for various compositions)

The HV laboratory offers:

- Withstand voltage tests and breakdown voltage tests up to 300 kV AC, 1 MV 100 kJ LI and 750 kV SI
- ECI up to 20 kA at 50 - 400 kV
- PD measurement with background noise <1pC
- Measurement of R, L, C and tan delta parameters up to 300 kV with Tettex 2840 electronic bridge

External users can gain open access to CVVOZEPowerLab for educational, research and non-commercial purposes.

Tettex Precision Oil and Solid Dielectric Analyser




Haefely Standard Capacitor

## Research activities

- research in high voltage area focusing on the measurement of electrical parameters and the degradation level of liquid as well as solid dielectrics. In addition to heat, the degradation effect was intense ultraviolet radiation, high-frequency electric field and DC electric field. The research results are presented in international journals.

- Ablation of PMMA, Evolution of composition and temperatur, usage of results for development of contactors

- Calculation of absorption coefficients of plasma mixture of C2F4 and CO2 (within the frame of SF6 replacement)

## Partnerships

- Faculty of Science, Masaryk University – research of gliding arc
- E.ON - Protection of human body against fault arcs

## Publications

[1] KRBAL, M.; PELIKÁN, L.; ŠT-PÁNEK, J.; ORSÁGOVÁ, J.; KOLCUNOVÁ, I. A Physical Calibrator for Partial Discharge Meters. ENERGIES, 2019, ro-. 12, -. 11, s. 1-10. ISSN: 1996-1073.

[2] KRBAL, M.; ŠT-PÁNEK, J.; PELIKÁN, L.; ORSÁGOVÁ, J.; KOLCUNOVÁ, I. Comparison of Electric and Radiometric Methods for Liquid Dielectric Diagnostic. Przeglad Elektrotechniczny, 2019, ro-. 6/2019, -. 04, s. 15-22. ISSN: 0033-2097.

[3] KRBAL, M.; ŠT-PÁNEK, J.; NEKVAPIL, J. Analysis of Liquid Dielectrics by Photometric Instruments. In Proceedings of the 2018 VII. Lighting Conference of the Visegrad Countries (Lumen V4). 2018. s. 138-141. ISBN: 978-1-5386-7923-4.

[4] KRBAL, M.; ŠT-PÁNEK, J.; WASSERBAUER, V.; ORSÁGOVÁ, J.; SUMEC, S. High Voltage Current Analyzer with Galvanic Separation. In Proccedings of the 2018 19th International Scientific Conference on Electric Power Engineering (EPE). 1. 2018. s. 314-318. ISBN: 978-1-5386-4612-0.

[5] KRBAL, M.; PELIKÁN, L.; ŠT-PÁNEK, J.; WASSERBAUER, V.; ORSÁGOVÁ, J. Improving the Operating Parameters of the 300 kV AC Test System. In Proceedings of the 2019 20th International Scientific Conference on Electric Power Engineering (EPE). Ostrava: VSB - Technical University of Ostrava, 2019. s. 364-369. ISBN: 978-1-7281-1333-3.

[6] KLOC, P.; AUBRECHT, V.; BARTLOVÁ, M. Pressure dependence of the optimised mean absorption coefficients. Novi Sad, Serbia: Serbian Academy of Sciences and Arts, 2018. s. 171-174.

[7] ŠIMEK, D.; DOSTÁL, L. Thermal Design Related Errors of Assemblies for Constructing Sites Discovered During the Temperature Rise Tests. In Proccedings of the 2018 19th International Scientific Conference on Electric Power Engineering (EPE). first. Brno: Brno University of Technology, Faculty of Electrical Engineering and Communication, Department of Electrical Power Engineering, 2018. s. 355-358. ISBN: 978-1-5386-4611-3.

[8] ŠIMEK, D.; DOSTÁL, L.; VALENTA, J. Detection of Local Softening, Welding and Formation of Metallic Bridges between the Copper Contact Pair Using Temperature Measurement. In Proceedings of the 2019 20th International Scientific Conference on Electric Power Engineering (EPE). first. Ostrava: VSB – Technical University of Ostrava, 2019. s. 118-121. ISBN: 978-1-7281-1333-3.

# FREESI Lab Expanding Facilities

- High Voltage & High Power
- Microgrids & Distribution Network
- Power Electronics
- Power Quality & EMC
- Storage Systems
- Smart Grid / Buildings
- ICT
- Cybersecurity
- HIL / Co-simulation
- Education & Training

University of Vaasa

**FREESI** is one of the laboratories of the multidisciplinary research platform VEBIC at the University of Vaasa. The research and testing activities focus on grid integration of inverter based DER and protection of power systems utilising also the facilities at the Internal Combustion Engine (ICE) laboratory.

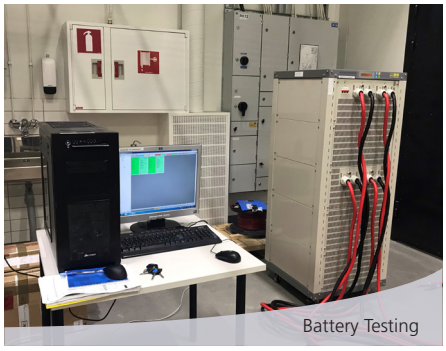
**infrastructure.der-lab.net/vaasa**

In the FREESI lab the setting-up phase of the OPAL-RT OP5600 based real-time simulation platform, with CHIL capabilities, was finalised in spring 2019. For the CHIL studies the simulator can be connected to the protection or any other IEDs using Omicron amplifiers and IEC61850 based communication.

Also, a new power electronic test system was acquired for the DER studies consisting of two DC/DC converters 500V, 40A each, a three-phase two level DC/AC inverter 1000V at DC side, and AC side power about 40kVA. As control unit, there is dSPACE MicroLabBox and dSPACE DS1104 board.

### New capabilities in 2020

Several new facilities are planned to be installed in the FREESI lab in 2020. One of them is a real-time co-simulation platform of power system and communication networks aimed especially for cybersecurity studies. Next, the microgrid test environment is being started with PV and battery system emulators accompanied later with a grid emulator.



Battery Testing

Further, there will be also a battery cell testing system with the capabilities of 4-channel battery cycler with high current (up to 300A) charge/discharge profiles and an advanced thermal chamber. For the high voltage testing, the plans include data acquisition system/commercial PD monitoring system, high frequency sensors with the focus on capacitive, inductive, and acoustic sensing.

### Consulting services

FREESI lab provides various services to external companies. We have long experience in simulation services relating to transient phenomena, especially various faults, in distribution systems. Testing services have been offered primarily relating to modern protection IED testing and CHIL tests with the real-time simulation platform.

Power Electronics

## Research activities

The research activities at the FREESI lab have been focusing mainly on the fault management in the distribution networks, control of DER, microgrids, and flexible energy resources as an integrated part of the grid.

With the new real-time simulator first major CHIL simulations included differential relay studies with two different setups. First, the effects of different behaviour of CTs and current sensors were studied. Then a more advanced setup was created enabling the studies of various IEC61850 based process bus configuration.

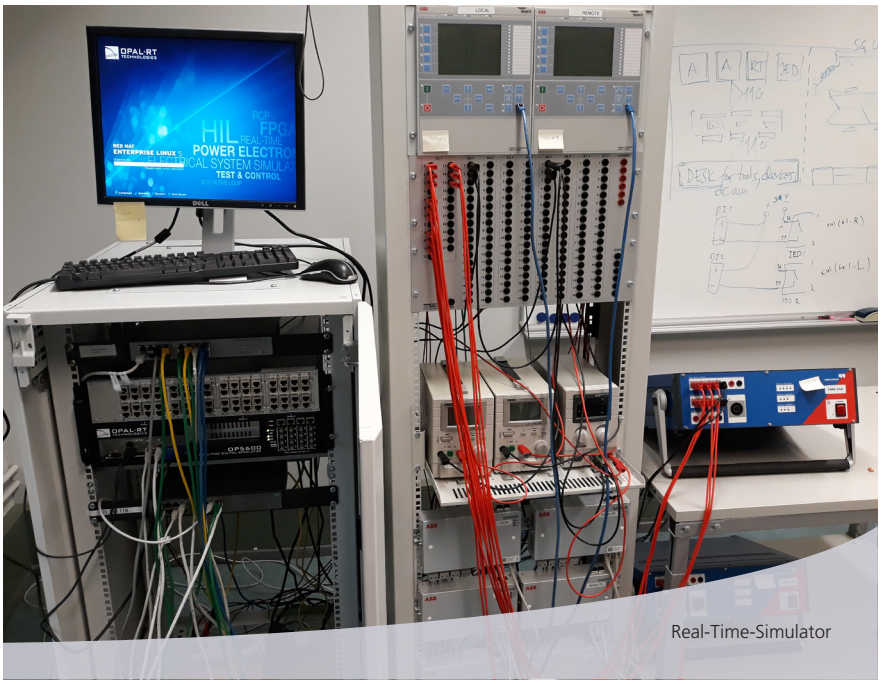
In collaboration with OFFIS, Germany, advanced simulation studies were made concerning the reactive power management of a medium voltage network utilising the reactive power capabilities of a wind power plant. The power system load flow and control were modelled with ePHASORSIM and eMEGASIM platform, and the reactive power control was accomplished with a light-weight IED, IEC61850 based controller. Real measurement data from the living lab site Sundom Smart Grid was utilised in this study.

The high voltage research activities were carried out for improving the reliability of grid operation by developing proactive online condition monitoring techniques and studying the aging behaviour medium voltage underground cables. This work has been based on experimental investigation for the incipient faults using partial discharge measurement and analysis.

## Partnerships

During 2018-2019 the research groups at FREESI lab have established and strengthened collaboration with international partner, including OFFIS (Germany), NTUA (Greece), Politecnico di Milano (Italy), and INESC-TEC (Portugal).

In addition to this more than 25 companies located both in the Vaasa region and elsewhere in Finland have been partners cooperating in the national projects. There is also collaboration with foreign companies, for example, with the Rugged Monitoring (Canada), relating to the PD measurement studies. Furthermore, a large number of new collaborations are being established in the joint EU Horizon2020 research.



Real-Time-Simulator

**Cooperative scientific articles by DERlab e. V. (DERlab member institutes) 2018-2020**
non-exhaustive list, more at **der-lab.net**

| Title | Authors | Place of publication | Affiliation |
|---|---|---|---|
| **Enhanced Load Frequency Control: Incorporating locational Information for Temporal Enhancement** | M. H. Syed[1], E. Guillo-Sansano[1], S. M. Blair[1], G. M. Burt[1], A. M. Prostejovsky[2], E. Rikos[2], | IET Generation, Transmission and Distribution Vol. 13, Issue 10, 21 May 2019, p. 1865-1874 | [1]**University of Strathclyde**, [2]**DTU**, [3]**CRES.** |
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Königstor 59
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Email: office@der-lab.net

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Authors: representatives of DERlab member institutes; DERlab Office
Coordination: Maria Sosnina, Dr. Diana Strauss-Mincu, Melissa Setakhr
Layout and editorial work: Maria Sosnina, Melissa Setakhr, Anna Gerbig

**DERlab e. V. Office**

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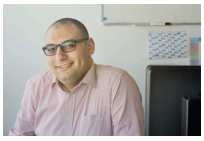

Mohamed Shalaby
Research Coordinator

Maria Sosnina
PR and Communications

Melissa Setakhr
PR and Communications

Ata Khavari
Project Manager and Researcher

Dr. Ron Brandl
Project Manager and Researcher

Keerthi Vishwanath A. R.
Researcher

Kai Dietrich
IT Administrator

Anna Gerbig
Student Assistant

Sören Lohr
Student Assistant

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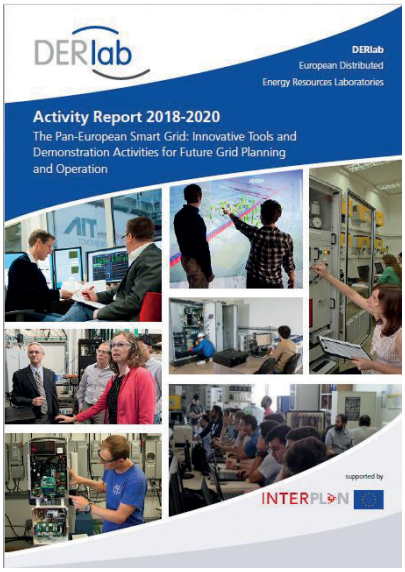


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