INTERPLAN
INTEgrated opeRation PLAnning tool towards the Pan-European Network

Work Package WP2

Technical assessment and regulatory status of the European electricity grid

Deliverable D2.4

Grid Code Recommendations

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Table of contents

Abbreviations

BRP	*Balancing Responsible Party*
CRM	*Capacity remuneration mechanisms*
CFR	*Charging with Frequency Regulation*
DA	*Day-Ahead*
DER	*Distributed Energy Resource*
DG	*Distributed Generation*
DR	*Demand Response*
DSF	*Demand Side Flexibility*
DSO	*Distribution System Operator*
EU	*European Union*
EV	*Electric Vehicle*
FFR	*Fast Frequency Response*
GA	*Grant Agreement*
ID	*Intra day*
PC	*Project Coordinator*
mFR	*mechanical Frequency Regulation*
MSs	*Member States*
RES	*Renewable Energy Sources*
SCN	*Subversion*
SO	*System Operator*
SOGL	*System Operation Guideline*
TSO	*Transmission System Operator*

Executive Summary

The INTERPLAN process to engage stakeholders and get feedback on the INTERPLAN activities consists of three steps:

- The consultation process.
- The organization of the workshops
- The targeted interviews

All three steps are building on each other and aim to provide targeted feedback on specific questions that are detailed enough to get meaningful response to complex issues and these are targeted in the next.

- The consultation process is based and built on the main outputs of Deliverable 2.2 and the INTERPLAN Use Cases[1] .
- Two workshops have been organised so far. The 1st workshop content was based on the knowledge of the consortium insight regarding the operational challenges of the operators and validated by the stakeholders. The 2nd workshop content was based on the main output of the 1st workshop, the consultation process and the Deliverables D5.2[2] and D5.3[3] on the INTERPLAN tool and INTERPLAN control functions.

The targeted interviews are based on the main outcomes of the 2nd workshop where selected stakeholders are approached to give their opinion regarding identified needs. So, this deliverable focuses on the identified last step of the process for validating achieved results and outcomes of the INTERPLAN project through extensive deliberations with a brought spectrum of stakeholders representing the industry as a whole. This is a natural continuation based on the outcomes, followed by the INTERPLAN consortium as already described in D2.3 "Targeted workshops with the stakeholders"[4]. The described process is depicted in the next figure.

Figure 1 The process of getting stakeholders feedback

[1] https://interplan-project.eu/wp-content/uploads/2018/11/D3.2-INTERPLAN-use-cases.pdf
[2] https://interplan-project.eu/wp-content/uploads/2020/06/D5.2-Operation-planning-and-semidynamic-simulations-of-grid-equivalents.pdf
[3] https://interplan-project.eu/wp-content/uploads/2020/06/D5.3-Control-system-logics-cluster-and-interface-controllers-first-version.pdf
[4] https://interplan-project.eu/wp-content/uploads/2020/08/INTERPLAN-D2_3_Targeted-workshops-with-the-stakeholders.pdf

This last step of the process, consists of the organization of the targeted interviews with the stakeholders as foreseen under the activities for validating the identified gaps and recommending possible amendments to grid codes and European regulations.

The main objective of the process with the experts was three-fold:

- The first is to elaborate further on the omissions and barriers of the regulations and codes on emerging technologies as identified under previous activities. So, experts would validate once more the outcomes of the previous two steps of the process.
- The second is to give their opinion and provide some recommendations on the identified omissions and missing links of grid codes and regulation policies at European level.
- The third is to evaluate as a whole the INTERPLAN solutions that the project offers for addressing the operational challenges. Also, focus was given to the recommendations for the INTERPLAN tool enhancement in the future.

Under this prism, the main points of this process that are worth highlighting are:

- The interviewees were carefully selected and approached so that we capture the views of all sectors of interest i.e. regulations, policy, transmission and distribution operation.
- The targeted interview process was based on the main findings of the Deliverable 2.1[5] , Deliverable 2.2[6] and Deliverable 2.3[1] complimented with specifically drafted factsheets summarizing the key outcomes of the project. The factsheets can be found in the annex of this document.

Based on the outcome of the interviews, it is considered that the adapted process was successful with rich feedback that is presented in the sections of this deliverable.

It can be safely said, that the high-level objectives of the INTERPLAN project are aligned with the needs of the industry delivering results that were evaluated by the approached stakeholders as valuable to the grid operators. The improved analytical capabilities that are supported by the proposed solutions of the INTERPLAN tool are found by the approached stakeholders as responsive to the needs of the operators for planning and operating the emerging integrated electrical grid of 2030 and beyond. Finally, they have all confirmed that if the INTERPLAN tool is made commercially available, they would use it complementing where needed the already excellent analytical tools that they are equipped with but all admitting that they face the shortcomings that correctly have been identified by the INTERPLAN project through the referenced deliverables.

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5 https://interplan-project.eu/wp-content/uploads/2018/07/INTERPLAN-D2.1_Limitations-in-the-analytical-tools-of-the-interconnected-grid.pdf

6 https://interplan-project.eu/wp-content/uploads/2019/09/D2.2_Grid-Code-and-regulation-limitations.pdf

1 Introduction

This deliverable focuses on the identified last step of the process for validating achieved results and outcomes of the INTERPLAN project through extensive deliberations with a brought spectrum of stakeholders representing the industry as a whole. Hence, this deliverable focuses on the main outcomes of the targeted interviews as the last step of the process that the INTERPLAN project has followed.

This last step of the process was taken to secure highly efficient and targeted feedback and validation from stakeholders especially in COVID-19 times.

1.1 Purpose of the Document

The main purpose of this document is to present in a structured way the targeted feedback from stakeholders and share recommendations for amendment on the grid codes and regulations related to the emerging technologies (storage, Demand Response (DR), electric mobility and renewables (RES)). In specific, the stakeholders' feedback is to elaborate further on the shortcomings and barriers of the regulations and codes on emerging technologies as identified under previous activities of the INTERPLAN project. Hence, a brought team of experts representing the stakeholders of the industry, are conducted in an attempt to validate and endorse what the INTERPLAN consortium has identified while discussing at the same time the required amendments and / or extensions of grid codes and regulation policies at EU level.

1.2 Scope of the Document

The main scope of the document is to present:

- The stakeholders' feedback on the missing links regarding **regulations and codes** and extend/amend where needed as well as recommendations on how the omissions can be tackled
- Review the adapted approach and achieved **technical solutions** of the INTERPLAN project.

For this purpose, INTERPLAN partners have interacted with selected stakeholders using a carefully selected set of questions that have already been presented in Deliverable 2.3 and also quoted here with necessary amendments dictated by the experience gained during the development work of the INTERPLAN project. In order to be able to address the issues presented above as well as to be prepared for different background knowledge of the stakeholders, the question are grouped in those tackling aspects regarding grid codes and regulation and those focussing on technical issues of the developed toolset.

1.3 Part 1: Questions of the targeted interviews related to codes and regulations

1. Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for grid connection of emerging technologies? Can you propose ways to overcome them?
2. Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for grid integration and operation of emerging technologies? Please give us your opinion on the low inertia systems and related operations such as voltage/reactive power control, provision of tertiary control reserve and congestion management if not included in your list of three top needs.
3. Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for the market covering the emerging technologies? Please give us your opinion

with emphasis on the ancillary services and in complementary markets such as flexibility market if not included in your 3 top needs.

4. Do you consider that non-viable business model for emerging technologies hinder their integration? Please expand. If yes, what is the main reason for having non-viable business models? Any recommendations on how we tackle them?
5. Can you please elaborate on the status of the regulations related to emerging technologies (connection, operation, market) in your country (few lines)? Is there any hindering regulation? (please provide name, link and your reasoning for classifying it as hindering) Any recommendations on how we tackle them?
6. Can you make an estimation on when the integration of the emerging technologies would be real and functioning in your country? (a few lines and in addition your reasoning)
7. Can you name/prioritize three top needs for guiding the effective collaboration between TSOs and DSOs? Any good code to follow?

1.4 Part 2: Questions of the targeted interviews INTERPLAN tool related

1. The challenge: Voltage profile with high RES	Utilization of reactive power provision capabilities of RES and DER in the distribution grids to increase the RES hosting capacity by controlling voltage profiles and preserving them within nominal limits both in transmission and distribution grids.
The INTERPLAN solution	Innovative distributed control schemes are provided acting through the advance features of RES and DER controllers to adapt dynamic operation in operational modes that will provide the required VAR needs to maintain the voltage within a preselected level or range. As can be appreciated, this distributed control regime acts hierarchically with central systems in providing the required reactive power supply to satisfy the needs of system voltage by using the advance features of inverter-based controllers embedded on the distributed RES and DER systems. This, to a large extent, will replace the VAR needs from large controlled bulk central power plants.
Do we address adequately the challenge?	**Input required**
Recommendations for enhancement of the control function	**Input required**

2. The challenge: TSO & DSO in coordination	To facilitate the new services in the European electricity market, the long-term congestion should be solved through flexibility services. Also, as far as the balancing is concerned, optimization of the power flow between TSO and DSO should be secured.
The INTERPLAN solution	INTERPLAN proposes two types of control functions to address the issue of balancing and congestion management through a coordinated scheme of TSOs and DSOs. In the proposed solution for balancing, DSO takes active part in power balancing, using its controllable assets for optimizing energy flow between TSO and DSO networks, while considering power losses and aiming to maximize utilization of RES, whereas in the proposed solution for congestion management, emerging technologies at distribution level are used to mitigate congestions at all network levels.
Do we address adequately the challenge?	**Input required**
Recommendations for enhancement	**Input required**

of the tool	

3. The challenge: Low inertia with high RES	The growing penetration of RES and DER impacts the healthy operation of the power system, exposing it to instability issues that are related to the low inertia of the resulting system.
The INTERPLAN solution	INTERPLAN simulates and validates several solutions that respond to the low inertia syndrome and address the resulting frequency control issues. They aim to provide frequency stability through the provision of frequency tertiary control/reserve by involving to the degree required the flexible resources available at both transmission and distribution levels i.e storage, flexible load etc. and their inverter-based controllers. This is done through optimal power flow calculations that self-identify the inertia condition of the system under investigation and activate appropriate levels of synthetic inertia that optimally meet the requirements of the system.
Do we address adequately the challenge?	**Input required**
Recommendations for enhancement of the tool	**Input required**

4. The challenge: Ancillary services with high RES	With the increasing penetration of DG / DRES operators should secure their contribution to ancillary services while minimizing energy interruptions
The INTERPLAN solution	INTERPLAN proposes a solution to optimally dispatch the generation in order to secure security of supply to critical loads after the contingency in grid. If the contingency results in an island that can be operated as microgrid, the INTERPLAN solution dispatches the generators and interrupt the non-critical and controllable loads at the supervisory level. This tool at the operational planning stage can be used to identify the requirements in terms of dispatchable generation and load shedding that are necessary to secure the operation of critical loads and maintain desired reliability metrics. The contingency situation can also lead to grid congestion therefore INTERPLAN tool prioritize available resources in order to minimize the congested lines and transformers
Do we address adequately the challenge?	**Input required**
Recommendations for enhancement of the tool	**Input required**

5. The challenge: Use of equivalents of sections of the grid	With the growing complexity of the integrated grid with active sources of energy connected at all levels of the system resulting in to bi-directional flows of energy and data, optimal operational planning of the system calls for complete system analysis with appropriate models for all connected resources.
The INTERPLAN solution	INTERPLAN proposes generic methodologies to build features for grid clustering and equivalenting in order to simplify the simulation of the complex interconnected system to the degree required that will facilitate full analysis of the section of the interconnected grid which is of interest to meet the specific operational needs. These, will be available to both TSOs and DSOs in the form of library selection to facilitate appropriately their specific needs without disclosing details of their interconnected systems. The targeted grid equivalents will contain to the degree required, time series of the active connected systems within the specific area, represented by the equivalent circuit to facilitate the analytical needs of the interconnected grid.

Do we address adequately the challenge?	**Input required**
Recommendations for enhancement of the tool	**Input required**

1.5 Structure of the Document

The document is structured as follows: Next section presents the first part of the interviews' findings regarding the grid barriers and shortcomings based in each question. the third section presents the second part of the interviews focusing on the feedback on the technical solutions. Section four presents the discussion on general recommendations regarding the codes and regulations while the responses received on the fifth question provide the concluding remarks on the value of the delivered solutions of the INTERPLAN tool.

2 Grid Barriers and shortcomings based on the targeted interviews-Part 1

As already mentioned, the targeted stakeholders are coming from the operators (DSO-TSO), policy and regulation side and were carefully selected in order to have a good and balanced overview of all activities in the field. For each question, a consolidated text is provided based on all stakeholders' feedback. It is critical to mention that none of the generated feedback is conflicting. On the contrary, views and opinions received complement each other and collectively are presented below:

What was put forward throughout the interviews is the notion that the system as it stands and operates is made for centralized conventional plants to be integrated in, therefore, the main challenge here is to address the questions of

- how much and what steps we can take to stretch this system and "fix" it as far as we can and
- how we can secure to run the system with the so-called emerging technologies that will be dominant, replacing traditional plants?

Having said that, a lot of work examining all possible alternative solutions for the future power system with all the emerging technologies playing an active role and then proceed with mature regulations and codes following an organised process of development- a long period of processing- to have a functional power system offering secure and resilient services to the users. In the following figure, the policy options and the tools in order to tackle the regulatory gaps are shown.

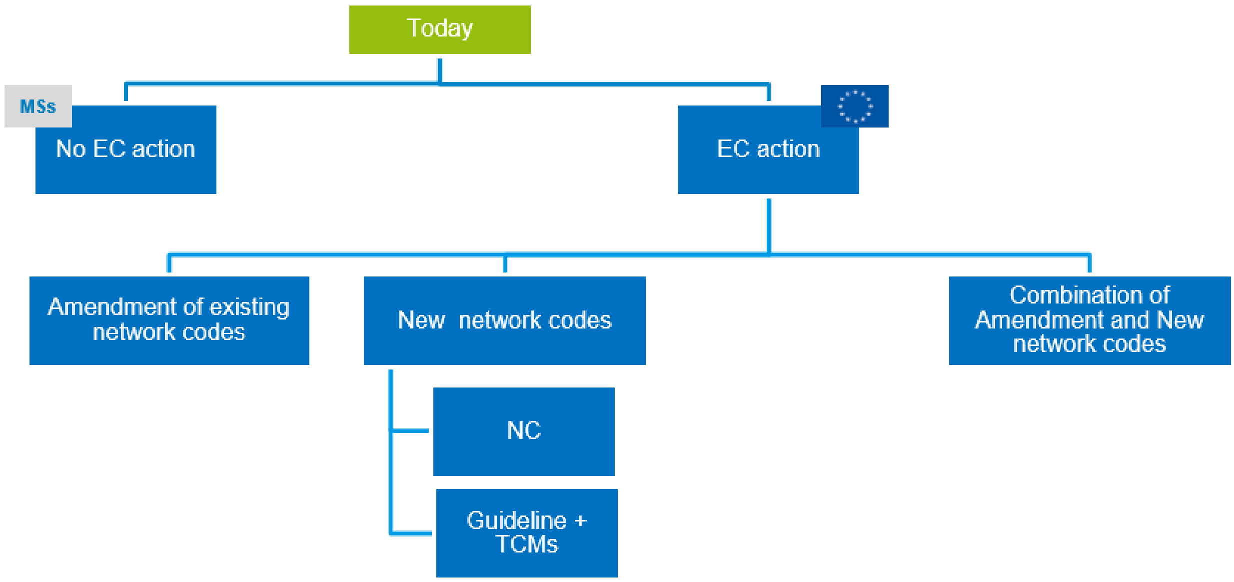


Figure 2 Policy options for tacking the regulator gaps[7]

(NC – Network codes, TCM- Terms, Conditions and Methodologies)

Another general issue that was raised by interviewees is whether codes for DSO-TSO cooperation are needed and if yes what issues should they cover. All interviewees have agreed that for flexibility issues they are definitely needed together with the market implementation. But how about ancillary services that are well performed every day by operators? To what extend should new related codes be defined? These challenging questions, of course, have a complicated answer but the main and first issue before attempting to answer is to describe efficiently the problems and the challenges that

[7] ASSET Study on **Regulatory priorities for enabling Demand Side Flexibility, European Commission**

the operators are confronted with under the new active integrated grid and provide recommendations on related codes and regulations. And this is the main focus of this part of the interviews.

2.1 Question 1 on shortcomings of regulatory framework for grid connection

Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for grid connection of emerging technologies? Can you propose ways to overcome them?

Interviewees underlined that the **main shortcomings** in the regulatory framework that need to be addressed and that now are missing in many EU countries are the following:

- Cost elements in connection grid rules and related authorization issues are not defined for storage.
- Storage connection rules cover RES technologies and partly batteries i.e. not all storage options are covered.
- E-mobility as a source of flexibility isn't addressed.
- DC connected systems are not covered by connection rules.

Recommendation to overcome them:

- Connection rules should include and specify cost elements of all emerging technologies especially for storage and DC connected systems as these are in general missing.
- Authorization issues related to Distributed Generation (DG) connection is also an issue that needs to be addressed as is the most hindering issue for grid development and RES integration. A transparent process is needed especially when hybrid systems are to be integrated i.e RES with storage that may possibly affect the environmental surroundings. This is a problem to be solved with a balanced approach between localized and central planning of the grid to make sure that the new DG that is going to connect (i.e. technology, size) serves not only the private investor but also the local grid and the grid development as a whole.
- DC related regulations especially with the emergence of the local energy communities' concept should be a priority.
- Storage when sparingly is included in codes is limited to batteries. Codes should include more storage options so as not to favour any technology and especially should include multi sector system integration in storage. Market based solutions are required to facilitate connection grid rules that are not biased basing development of the flexible capabilities of emerging technologies thus development of the system is optimal and technology neutral.
- E-mobility and how electric vehicles (EVs) are going to be integrated as a flexibility resource capable of offering valuable services to the integrated grid are lightly addressed in some countries such as Greece but many countries are far behind. Amendment of the current codes or new codes on electric vehicles should consider EVs as a non-fixed point of energy but rather as a roaming service in Europe.

2.2 Question 2 on three top needs for regulatory framework for grid integration and operation

Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for grid integration and operation of emerging technologies? Please give us your opinion on the low inertia systems and related operations such as voltage/reactive power control, provision of tertiary control reserve and congestion management if not included in your list of three top needs.

Validation and the needs: The main challenges are related to the operation codes that deal with the flexibility and storage as already mentioned in the connection codes section. It has to be mentioned that these codes should be technology neutral and serve the functionalities and operations of the grid. The codes should be seen as having two dimensions. The first dimension is how to include the capabilities of the new technologies to the traditional operation of the grid and thus to focus on the amendments that are needed in the existing codes. The second dimension is how to develop from scratch codes that support the new functionalities and unlock the capabilities of the new technologies.

Regarding the congestion of substations, it needs to be regulated in order to host more emerging technologies and harmonized as definition of services provided. In the following table the regulatory gaps regarding the congestion management are summarized[8] with the understanding that these are published in 2019 and nothing has improved since then. Of course, the gaps are linked with the market and how the operators would coordinate to tackle the congestion. At this point, the amendment of the existing regulation such as the enhancement of DSO role is highlighted.

Storage has a long way to go before delivering its wealth in the emerging needs of the grid of 2030 and beyond. For example, storage is considered in Germany to be operating as an electric load. Thus, current regulation has inherent problems since the storage owner pays twice grid fees: once for charging and secondly for delivering energy to the grid.

Recommendation: There is a need to be at a point where the advanced services offered by emerging technologies should clearly be described in the grid rules of the country, quantified and rewarded on equal footing with other technologies offering the same service. The main operations that are identified and needed to be included in the future codes are listed below:

- Low inertia is the key -for the TSO- and especially **fast response reserve**. A threshold should be defined: this can be as to when does low inertia has to be complemented by emerging technologies as a function of power delivered.
- A similar approach should be approached for **reactive power provision for voltage control.** This is another operation that calls for a careful management control to be included in the regulations not only for the required operations but also for the needs of the market.

Regulatory Gaps

The current EU regulatory framework fails to provide a clear picture as to how these design features would look like in the context of grid congestion management

Key Design Features	Regulatory Gaps*
Product definition	• Standard products have been defined for those that are traded in DA, ID and Balancing market but there is no harmonized product definition for congestion management (in the distribution grid) services at EU level • Products also require the definition of baselines, defined at the necessary geographical granularity
Market delineation	• The current bidding zone definition methodology focuses on the transmission level and it is not clear if distribution grid constraints are considered • There is no clear framework on the possibility of creating bidding zones at distribution level
Platform operation (and ownership)	• There is no regulatory framework defining the roles and responsibility of market stakeholders including as to who should own and/or operate TSO-DSO coordination platforms and flexibility trading platforms (TSO, DSO, PXs)
TSO-DSO Coordination	• Existing network codes address TSO-DSO coordination with a limited scope on the evolving role of DSOs to procure local flexibility in a market-based approach to actively manage their grids • Both the SOGL and EBGL focus on transmission system operation while limiting the role of DSO to prequalification and provision of information for imbalance settlements • There are no clear provisions that set technical prerequisites and operational principles concerning the ability of the DSOs to have sufficient observability (actual & forecasted state of the grid) and controllability (activation with verification)
Integration with existing markets	• The position of CM market in the current market sequence is not clearly defined at EU level • No guidance on the representation or internalization of cost of distribution grid constraints in the existing wholesale markets, • Most discussions are focused on separate markets for CM services required by the DSO and if location dependent and non-location dependent products are coupled. The focus is on who uses the bids first, second and so on (e.g. TSO -> DSO -> BRPs)

Figure 3 Regulatory gaps in the congestion management at EU level[7]

- **Self-healing of grid forming capabilities** is an issue that will help the continuity of supply and avoid black outs in the future or minimise the restoration time especially needed in countries such as Italy due to its geographical characteristics. Also, the islanding mode of operation that is much needed, is going to be supporting by these types of capabilities.
- **Congestion management and Demand Response (DR)** are operations that need to be included under the proposed context. In specific, smart demand response is needed, meaning a dynamic relation with the consumers or smart load shedding. Persisted

[8] *https://ec.europa.eu/energy/sites/ener/files/documents/EG3%20Final%20-%20January%202015.pdf*

congestion needs reinforcement and development of the grid but casual congestion can be addressed by flexibility services and thus DR.

- **Long term storage services** are an operation of importance for the future too and yet not thoroughly addressed. Thus, tertiary reserve regulations should extent to capture that and the reward for these services again should be defined. A suggestion for addressing this issue, is to have two remuneration parts: a fixed revenue for providing the reserve capacity and a variable part of revenue when asked to go into operation servicing the needs of the grid. This need springs from the fact that such investments are of high capital expenditure requiring substantial time to be developed and payback period is over a much longer period with uncertain revenues as is the case with current cold reserve of the system. But for quantifying these operations that are delivered and thus appropriately rewarded we need appropriate market rules to be designed as will be discussed in the next question. This calls for both regulators and operators come in close collaboration to secure that appropriate market rules come in place.
- **Resilience planning** to be included in the day to day planning and operation needs of the operators that can influence how they develop the grid and make it responsive and resilient. The regulators should address this need and include a cost compensation or an appropriate regulatory incentive to the operators for this kind of service.

2.3 Question 3 on three top needs for regulatory framework for the market

Can you name/prioritize three top needs for the shortcomings identified in the regulatory framework for the market covering the emerging technologies? Please give us your opinion with emphasis on the ancillary services and in complementary markets such as flexibility market if not included in your 3 top needs.

The main challenge regarding the market regulations is how to organise a market for a product where there is no marginal cost. How to integrate RES into the market? Capacity defined by flexibility is the only product that can be traded. How equal footing is to be given to the emerging technologies in the different markets?

Validation and the needs: Market codes are left behind although important steps forward for the wholesale markets have been taken. So as for now, there is a good alignment and a good harmonization for balancing frequency market (*mechanical Frequency Regulation*- mFR, *Fast Frequency Response*- FFR, *Charging with Frequency Regulation* -CFR). Still the congestion market where the TSO-DSO collaboration is implied and already mentioned before is highly immature. The same stands for the ancillary services market that are not frequency related and are absent and needs to be included in regulations. It has been identified that the market integration with other sectors is not mature as needed. Also, under the energy communities concept retail and local markets are not yet addressed by the codes. So, small consumers and owners of emerging technologies are left behind.

The **main need** for the operators is a panel of different technologies- and aggregation of them- with different services and characteristics and costs.

Demand Response (DR) is missing in most markets of the European countries.

Storage has no incentive for operating and participating in the market in many countries including today's regulation as there are no regulations for exchanging power with the grid. Also, there are no incentives for providing advanced operations e.g. the balance clearing cycle.

No framework for the upper limit of the **Distributed Generation penetration** in the grid exists. To define this limit some ancillary services, need to be taken into consideration apart from the limit resulting from the technical constraints of the grid. And this is quite a challenge as the market regime is absent.

Regarding RES penetration and how this is taken up by the market is an issue that it is still immature.

Flexibility is a hot topic from regulatory point of view. Most tools that are implemented are TSO oriented and try to help DSOs as well. But the main challenge is how to jointly plan flexibility for both DSO and TSO. What are the relevant needs for both of the operators and how these are addressed. To tackle this, Demand Side Flexibility (DSF) is needed and to identify the golden point where both operators find this beneficial in addressing their needs. DSF has a lot of potential, but its framework is not specified yet. The following definition is given by CEER[9]:

DSF can be defined as the capacity to change electricity usage by end-use customers (including residential) from their normal or current consumption patterns in response to market signals, such as time-variable electricity prices or incentive payments, or in response to acceptance of the consumer's bid, alone or through aggregation, to sell demand reduction/increase at a price in electricity markets or for internal portfolio optimisation.

The **aggregation framework** defines how aggregators can participate in wholesale and balancing markets. The framework sets out the baseline methodology for assessing flexibility services and transfer of energy provided by aggregators. It will capture the measurement, validation and settlement procedures for aggregators and customers. The aggregation framework is significantly important for cross-border trade. Ensuring a clearly harmonised aggregation framework for participation in energy markets, enables aggregators and end consumers to leverage the benefits of cross-border trade. Without standardised aggregation frameworks, aggregators will face differing requirements across Member States. These varying requirements could result in higher costs for aggregators to participate, resulting in a barrier to participation. A significant DSF barrier to provide flexibility services at wholesale/transmission is based in the absence of European frameworks for aggregation and prequalification processes are identified as the main barriers.

The Capacity Allocation and Congestion Management code **do not distinguish between types of market participants** e.g. aggregators in the details of the day ahead and intraday markets. The main barrier for DSF providing flexibility services at distribution level lies in the absence of a European regulatory framework for the development of a congestion management market.

Gap analysis of the codes based on the needs of the operators have been carried out in the past by the smart grid task force[10].

In the following figure the methodology that has been followed is presented in:

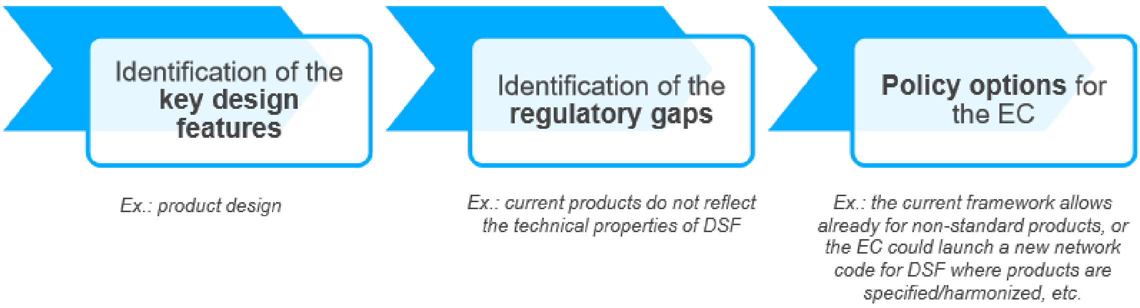


Figure 4 The methodology for identifying the policy options for regulatory priorities[7]

This way, the policy actions that needs to be taken before resulting to regulations and codes are identified. There are three policy competing scenarios identified: Bottom up approach, top-down plus

[9] https://www.ceer.eu/eer_publications/ceer_papers/electricity/citizens_q_a#

[10] SGTF-EG3 Report: Regulatory Recommendations for the Deployment of Flexibility. January 2015

the balanced.

Business As Usual Scenario

- No action (no revision of network codes) is taken by the EC in the coming years. All decisions are left to MSs.
- This is based on the idea that it is too early to intervene – there is still a need to gain experience before implementing new or adapting existing network codes.
- Many initiatives are taken today, and more are expected: DSOs, to be in line with the CEP, will organize their own congestion management market. Likewise, some PXs are also integrating local bids in their clearing, P2P platforms are arising, DSOs and TSOs coordinate their actions at different degrees, etc.
- It is very likely that a wide variety of local markets will appear (products, clearing, roles & responsibilities, timing, etc.).

Bottom Up Scenario

- The focus is on the treatment of congestion at distribution level and redispatch at transmission level that today cannot be handled by wholesale markets. DSOs take initiatives to procure DSF and other resources in a market-based way. TSOs do likewise.
- It is required that DSOs and TSOs coordinate. This coordination is important, in view of using DSF and other means to address congestion at local and at transmission level in the most efficient way.
- Most of the framework is already provided at European level but the EC intervenes to harmonize the design of the congestion management market.

Top-Down Scenario

- The current European target model is transposed to the distribution level
- (wholesale) markets internalize the grid constraints, leading to a nodal pricing system with the particularity that prices can have a distribution granularity (DLMP)
- Strong intervention by the EC at various levels

Figure 5 The three-competing policy scenarios.

Recommendation: Fundamentally the energy only market is not the right approach in a zero marginal cost system. All ancillary services are repairs to that wrong approach. It is also the cause of the enormous repairs like Capacity Remuneration Mechanisms (CRM), that make the prices unreliable. So, new market products that are well designed and support the operation as envisaged in the future are needed,

- Market products should be extended not only to the **primary reserve** e.g. from batteries but also to the other end of **tertiary reserve** e.g. from hydropower or hydrogen. A proper reward should be designed for these services as well. A suggestion for doing so, is to have two parts for the remuneration as indicated above.
- regulations are required which include incentives for increasing the **self-consumption** of energy. PV owners and other emerging technologies owners together with energy communities can share a certain viable business model

Solutions provided by analytical tools should cover in addition to the above through responsive controllers the mechanisms developed through the market for providing the following:

- All forms of flexibility including DSF
- Congestion management
- Voltage support

2.4 Question 4 on non-viable business models

Do you consider that non-viable business model for emerging technologies hinder their integration? Please expand. If yes, what is the main reason for having non-viable business models? Any recommendations on how we tackle them?

Interviewees stressed that there is a need to forget the energy-only market. The real task is to make energy as a service to the consumer. High quality energy services -such as flexibility that consumers can be benefited from- are needed for consumers and not burden them with the operational problems of the grid. Thus, adaptation and how to utilise the emerging services replacing the current ones, is very important.

Business models hinder the emerging technologies integration due to lack of appropriate market rules and related policies. Grid fees need to be adjusted to capacity and energy portions reflecting the generated cost of the emerging services. How infrastructure is to evolve to meet the new operational environment has to be supported by business models, market set up and pushed by incentivised policies for emerging technologies to flourish. Infrastructures within the integrated system are intended to give value to the connected active elements and not outside. Thus, the business model as is today, facilitates and secures the smooth and economic operation of the current system not leaving any room for adaptation to incoming new actors and services, thus hindering the much-wanted evolution to be viable for all new actors' and allow them to act and grow. Interviewees underlined the fact that the system as is, it is not designed for active distribution to play a contributing role in the day to day operations.

It is of prime importance, to adopt policies' meeting the needs of designed scenarios that capture the needs of the system of tomorrow, thus viable models to pick up and grow.

2.5 Question 5 on status of regulation in the country of the interviewee

Can you please elaborate on the status of the regulations related to emerging technologies (connection, operation, market) in your country (few lines)? Is there any hindering regulation? (please provide name, link and your reasoning for classifying it as hindering) Any recommendations on how we tackle them?

Interviewees identified the need that regulationsshould urgently address interoperability issues as they are not tackled appropriately in the current codes of their countries. This is extremely important for the development and operation of the future grid. It is also important that emerging technologies like storage, EVs, DR and RES are regulated taking into considerations their valuable contribution to the integrated grid. Current regulations do not respond to this need and hence, the identified limitations that hinder their growth in support of the needs of the countries.

As an example of good practice, it was noted that in Belgium, there is a charge/tariff for every consumer for their average maximum demand from the system on an annual basis. This is a good practice to incentivize for the integration of emerging technologies such as storage, EV etc.

2.6 Question 6 on integration of emerging technologies in the country of interviewee

Can you make an estimation on when the integration of the emerging technologies would be real and functioning in your country? (a few lines and in addition your reasoning)

There was consensus among the interviewees that it is expected that by the end of 2021 most countries should have codes in place to facilitate the emerging technologies integration in response to the clean package legislation. In some countries as Belgium, it is a top priority to be be one of the first to go for capacity-based tariff based on actual measurements of peak demand for the emerging technologies and move away from energy related tariffs only. It was emphasized that Italy should act so that the distortion of the market through fiscal taxes on the electricity bills need to be amended. It was stressed that the demand response service will lead and open the way for many operations and emerging technologies' system integration. Both technical and economic optimal solutions are needed as well as incentives for consumers/citizens to have a facilitating behaviour and being in the centre of the system.

2.7 Question 7 on top 3 needs for TSO and DSO collaboration

Can you name/prioritize three top needs for guiding the effective collaboration between TSOs and DSOs? Any good code to follow?

From the discussions with the interviewees, the following three needs are qualified as of top priority:

- TSO-DSO do not have integrated cooperation up to now. The **flexibility provision** that the DSO can give to TSO is a critical issue to cooperate on. To this end, TSO-DSO **provisions need to be standardized** in order to guarantee the volatility of the market. Under this prism, the flexibility market as a new commodity/product calls for substantiated cost evaluation for the benefit of both operators.
- Increasing congestion issues in the distribution system should be handled by the local DSO using optimally local resources. This approach will maximise the use of available resources giving options for trading flexibility with the connected TSO through appropriate operational rules. If this is not done optimally inter-operators' problems will persist, and the TSO may be required to limit its available capacity cross-border, restricting cross-border trade. Therefore, TSO-DSO should coordinate **for congestion and balancing issues** through a common active management report and sharing data. This will definitely be helpful for integrated congestion and balancing market. As a result, the main recommendation is that data base should be one i.e. through a common data platform for the electric energy system. The rest will follow. DSO new obligations merge from the new legislation coming through the green package and operators need to include them into their 10-year plans.
- A Common hierarchical operational planning for the grid development and economic operation suggest an effective collaboration through appropriate analytical tools that capture the dynamic behaviour of all active contributors to the energy mix.

From the discussion with the stakeholders some good practical examples emerged. In Austria, a good cooperation scheme between the only TSO and DSOs are followed allowing DSOs to be responsible for operating the low voltage grid meeting their operational needs through local control. They are in collaboration with the TSO for scheduling and the measuring the quantities of interchanged power between them. For example, in case that connected wind capacity is more than the peak load and they need capacity to be absorbed by the TSO the following procedure takes place. All DSOs are in connection with the TSO following the well-known traffic light system to check whether they need to take or deliver power (including inter countries connection) to make sure that the wind power is optimally included. This needs to run a flexibility market for the excess power provided from the RES. This logic from the technical perspective has been used for the development of the INTERPLAN tool.

3 Stakeholders feedback based on the targeted interviews-Part 2

Last decades have been evolutionary in changing the grid as it has been known and fundamentally changed the way of the operation. To this extend, new tools and solutions that will facilitate the planning of the operators and give visibility throughout the grid are considered to be a part of the solution when reforming the gird. Currently there is a lack of analytical tools that facilitate the study of the grid in its entirety taking into consideration the contribution of the active network especially the contribution of the active elements connected on the low voltage level. Thus, currently operators are suffering from lack of observability of important contributors to the energy mix.

Following detailed discussions with a selection of stakeholders of the industry based on the following targeted questions we have put together their collective views in the following paragraphs. The views of the stakeholders are below in blue lettering

12. Challenge: Voltage profile with	Utilization of reactive power provision capabilities of RES and DER in the distribution grids to increase the RES hosting capacity by controlling voltage

high RES	profiles and preserving them within nominal limits both in transmission and distribution grids.
The INTERPLAN solution	Innovative distributed control schemes are provided acting through the advance features of RES and DER controllers to adapt dynamic operation in operational modes that will provide the required VAR needs to maintain the voltage within a preselected level or range. As can be appreciated, this distributed control regime acts hierarchically with central systems in providing the required reactive power supply to satisfy the needs of system voltage by using the advance features of inverter-based controllers embedded on the distributed RES and DER systems. This, to a large extent, will replace the VAR needs from large controlled bulk central power plants.
Do we address adequately the challenge?	We agree that the INTERPLAN solution mirrors the first line of response through the advance features of the inverter power electronics. The "master-slave" based control is gradually giving way to responsive controllers driven by active energy sources throughout the active grid. As VAR's is better generated or consumed locally voltage profile correction is considered a local action. To this extend, local energy sources should be responsible for voltage control offering the possibility of quality of supply at point of common coupling.
Recommendations for enhancement of the control function	• Define limits for VAR control at point of common coupling and smart nodes such as smart substations (be aware of undergrounding, giving serious problems) • Push each user (or group of users in a LEC for example) to solve the problems "behind the meter" or within their control area within the point of common coupling with the rest of the system.

13. The challenge: TSO & DSO in coordination	To facilitate the new services in the European electricity market, the long-term congestion should be solved through flexibility services. Also, as far as the balancing is concerned, optimization of the power flow between TSO and DSO should be secured.
The INTERPLAN solution	INTERPLAN proposes two types of control functions to address the issue of balancing and congestion management through a coordinated scheme of TSOs and DSOs. In the proposed solution for balancing, DSO takes active part in power balancing, using its controllable assets for optimizing energy flow between TSO and DSO networks, while considering power losses and aiming to maximize utilization of RES, whereas in the proposed solution for congestion management, emerging technologies at distribution level are used to mitigate congestions at all network levels.
Do we address adequately the challenge?	The interviewees collectively consider that the approach of the INTERPLAN project moves in the correct direction giving solutions that will enhance optimally the use of distributed resources for the benefit of the interconnected grid. In principle they agree with the proposed solutions. They underline though that the current situation is not mature as yet since the TSOs are still the dominant operator giving little to the DSOs. However, the green package and the legislation coming with it will dictate an active role to the DSOs maximising the benefits of distributed resources and DR flexibility. This will enhance the penetration of RES at the low ends of the grid, but we need to have in mind that curtailment is not always bad: you can have more RES by curtailing portions of it when there is surplus but overall offering more economical solutions (curtailing a peak with a higher overall generation might by cheaper overall)
Recommendations for enhancement of the tool	To enhance system view by considering. 1. TSO/DSO full cooperation in planning and operating the system of the future through system holistic optimization going beyond local economics.

	2. Optimal use of resources should also look at the best and most efficient way of using storage in a given system mix.

14. The challenge: Low inertia with high RES	The growing penetration of RES and DER impacts the healthy operation of the power system, exposing it to instability issues that are related to the low inertia of the resulting system.
The INTERPLAN solution	INTERPLAN simulates and validates several solutions that respond to the low inertia syndrome and address the resulting frequency control issues. They aim to provide frequency stability through the provision of frequency control/reserve via hierarchical controls by involving to the degree required the flexible resources available at both transmission and distribution levels i.e storage, flexible load, etc. and their inverter-based controllers. This is done through optimal power flow calculations that self-identify the inertia condition of the system under investigation and activate appropriate levels of synthetic inertia that optimally meet the requirements of the system.
Do we address adequately the challenge?	The interviewees consider that we need to rethink where we need to go and how the relevant codes representing the old system do not hinder the system evolution towards the low carbon mix. Optimal power flow on its own can never really take into consideration the available inertia. The issue is of how to define the inertia of an inverter-based system that can offer the required stability and resilience? Hence, the approach of the INTERPLAN project for introducing analytical capabilities for investigating the response of the system to disturbances and committing the respective system components that can offer the required inertia either as mechanical or synthetic and then move to the traditional analysis of optimal load flows, fault level calculations etc is moving in the correct direction. In relation to this issue, it was underlined that current systems like the one in Germany do not face the problem of low inertia due to extensive interconnections of surrounding systems. Other system characteristics like voltage is of more current importance especially when we are talking about thousands of km of transmission grid to reach consuming areas. On the other hand, TSOs currently lack the operational capabilities to identify what are the DERs within the gird and thus cannot see the urgency of developing solutions like the ones proposed by INTERPLAN.
Recommendations for enhancement of the tool	System analysis should hierarchically approach solutions using local resources and push the inverters to provide inertia like solutions to the maximum. Maximise the contribution of systems within buildings behind the meter for minimizing the needs hierarchically higher up i.e. substation, transmission, power station etc

15. The challenge: Ancillary services with high RES	With the increasing penetration of DG / DRES operators should secure their contribution to ancillary services while minimizing energy interruptions
The INTERPLAN solution	INTERPLAN proposes a solution to optimally dispatch the generation in order to secure security of supply to critical loads after the contingency in grid. If the contingency results in an island that can be operated as microgrid, the INTERPLAN solution dispatches the generators and interrupt the non-critical and controllable loads at the supervisory level. This tool at the operational planning stage can be used to identify the requirements in terms of dispatchable generation and load shedding that are necessary to secure the operation of critical loads and maintain desired reliability metrics. The contingency situation can also lead to grid congestion therefore INTERPLAN tool prioritizes available resources in order to minimize the congested lines

	and transformers.
Do we address adequately the challenge?	The interviewees have reacted positively to the proposed solutions by the INTERPLAN tool responding that the challenge is addressed adequately. They have indicated that as currently is practiced intermittent RES sources do not play a role in the traded ancillary services. Operational planning highly depends on conventional systems for providing the much-needed ancillary services and no tools are available for managing all resources on equal footing. For this reason, the interviewees were happy to see that the INTERPLAN tool was offering the analytical capabilities of managing the resources on equal footing with the objective of safeguarding quality of supply and minimize load interruptions. Seeing that the resources can be dispatched in coordination so as to maximize availability and minimize disruptions, have welcomed it that it is moving in the correct direction. To this effect, interviewees consider that the contribution of the emerging flexibility provided by EVs, DR and storage are the right answer for managing high RES penetration. Analytical tools should be capable of offering these capabilities and the interviewees have confirmed their satisfaction that INTERPLAN has correctly approached this real problem that current practices do not take it into consideration.
Recommendations for enhancement of the tool	• Extend the tool options to cover smart charging of EVs addressing Vehicle to Grid options as well hence, improved flexibility to manage congestion caused by e-mobility in the last mile when charging. The unbundled market with new actors appearing handling the charging infrastructure generates an added complexity but the grid planning using developed tools like the INTERPLAN should take into consideration the prevailing market rules(Unbundled market was) • Hence, different actors such as service providers will act through the prevailing market rules but the integrated grid needs to be analysed and developed taking all into consideration, thus tools like the INTERPLAN should be capable of managing needs of new actors in coordination with the RES systems as this objective can be contradictive.

16. The challenge: Use of equivalents of sections of the grid	With the growing complexity of the integrated grid with active sources of energy connected at all levels of the system resulting in to bi-directional flows of energy and data, optimal operational planning of the system calls for complete system analysis with appropriate models for all connected resources.
The INTERPLAN solution	INTERPLAN proposes generic methodologies to build features for grid clustering and equivalenting in order to simplify the simulation of the complex interconnected system to the degree required that will facilitate full analysis of the section of the interconnected grid, which is of interest to meet the specific operational needs. These will be available to both TSOs and DSOs in the form of library selection to facilitate appropriately their specific needs without disclosing details of their interconnected systems. The targeted grid equivalents will contain to the degree required, time series of the active connected systems within the specific area, represented by the equivalent circuit to facilitate the analytical needs of the interconnected grid.
Do we address adequately the challenge?	The interviewees have found a lot of interest in the methodology using system equivalents that ease complexity without losing performance and response of the network, which is presented through a twin equivalent. Thus, the complexity generated through the penetration of the emerging technologies in analyzing their contribution to the integrated active grid to achieve optimal solutions, is well covered by the introduction of network equivalents. Hence, this provision in the INTERPLAN tool is highly welcomed and it will certainly offer improved operational capabilities covering adequately the emerging system with active technologies throughout.

	During the discussion with stakeholders, it was noted that the term "without disclosing details of their interconnected systems" should not prevail, as this seems to be an unwanted lack of transparency.
Recommendations for enhancement of the tool	• Currently DSOs are running power flows to give the feedback to the TSO to use results for their calculations. The developed equivalents through the INTERPLAN project could replace this activity but the enabling of the consumers through the new legislation to be active participants, calls for enhanced models to capture this enabling need, thus it would be a recommendation of enhancement of this tool with an appropriate model and it certainly is in the right direction. • The enhanced analytical capabilities of the INTERPLAN tool should follow a route for standardizing this process in order to be used freely by operators and be in a position to exchange results and build cooperation etc.

4 Conclusions and general recommendations resulting from INTERPLAN project

4.1 General recommendations

Within this section, general recommendations are presented, based on the feedback from the series of interviews with stakeholders of the electricity industry: policy makers, regulators, TSOs and DSOs.

What was clear by the interviewees is the need to make sure that the approach for the new regulations and codes is not an attempt to fit the emerging technologies to the conventional generation based-centralized system but trying to resolve how this is being adapted to the new system where emerging technologies will be gradually the dominant ones. For the time being it is a transitional period / operational status and the system will gradually move towards the new major player which looks to be technologies based on power electronics and hence synthetic inertia instead of the traditional mechanical inertia.

The interviewees have shown evident support of the proposed solutions of the INTERPLAN tool considering them that:

- They are moving in the correct direction.
- They address shortcomings and limitations of current codes and policies that are fundamental in moving forward with the integrated grid that is planned for 2030 and beyond and in which the emerging technologies will play a very important role.
- The operators, both TSOs and DSOs will be happy to use analytical tools that are enhanced with the capabilities addressed by the INTERPLAN tool provided that such tools pass a rigorous proof of adequately representing the emerging technologies and proposed equivalents reflect correctly the system that they represent under demanding operational regimes.

In this process of transformation and evolution, the following points were noted by interviewees to be seriously taken into consideration may be through an extended life of the INTERPLAN project or through a new project that will build on the results achieved:

- There is a need for real system data that can feed in the tools of tomorrow for providing the much-wanted accuracy out of the proposed models. This enhancement will build a library of solutions that will be available for selection by system analysts with enough evidence as to the capabilities offered for operators to be encouraged to use them and depend on the evaluated outcome.
- Regarding the regulations that need to be amended or built from scratch for the emerging technologies there is a proposal to use both top-down and bottom up approach and find the golden equilibrium. This way, we can identify the matrix with the needs to change the codes

in the future and thus address efficiently the challenges.

- In the process of introducing new regulations a good practice is to make use of the sandbox framework. Through this approach, operators can relax regulation regime and thus different actors can apply different operations to reach optimal solutions. This can be a useful recommendation for the integration of RES and the flexibility that can be provided.
- Emerging technologies should not be seen as isolated technologies when developing the codes / regulations but as functional additions in supporting the system with much needed operational capabilities addressing real shortcomings and gaps.
- Sector coupling possibilities is a hot topic and needs to be taken on board in a future INTERPLAN enhancement aiming to enable optimal multi sector analysis for system development and operational planning of the system of 2030 and beyond.
- The accuracy of the equivalenting and clustering is critical for the effectiveness of the INTERPLAN tool and for operators to accept the developed solutions in their analytical portfolio, rigorous proof of results achieved should be included in future selection library provision accompanying the offered solutions.
- Due to the fact that centralised and decentralized type of energy markets will arise and the needs of local markets will call for cooperation between DSO-TSO, it is of vital importance that future versions of the INTERPLAN tool should include the market perspective offering a significant enhancement.

4.2 Regarding the flexibility

A separate list of recommendations is quoted as flexibility is of substantial importance for the emerging technologies utilization. ASSET project report[7] assists the Commission in defining the needs and scope of a regulatory priority list for DSF by defining policy options in view of implementing new or updating existing network codes by 2025. So, it is of substantial importance that the recommendations resulting from the INTERPLAN project interviews are aligned with the main outcomes of the ASSET report.

Main barriers of DSF to access existing organized electricity markets at the transmission level are schematically presented in Figure 7 below where DSF, and other distributed energy resources (DERs) connected to the distribution system are participating in the day ahead, intraday and balancing markets. The main barriers identified are related to the existing and to the new markets as have been already identified in sub section 2.3 and are shown in the arrows 1 &2 of the graph. More details on the barriers can be found in the ASSET report.

The INTERPLAN tool has introduced a first set of controllers for managing distributed flexibility but more development work is required to enrich the library of technical solutions considering the following needs for DSF use into the market.

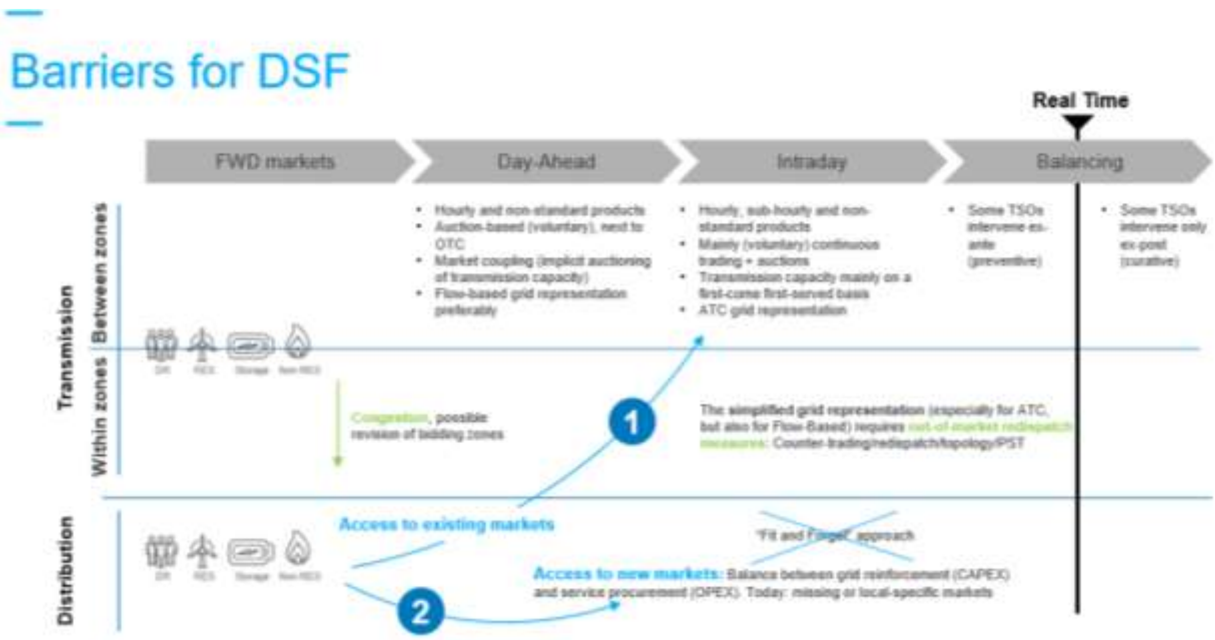


Figure 6 DSF integrated into the market and main barriers[7]

- Avoid contradiction & repetition with existing network codes. Key design features for congestion management market should be clarified. As mentioned in the ASSET report, leaving the design of such markets to the Member States is not recommended as future harmonization of national systems will be very challenging and time consuming to achieve.
- Differentiate what needs to be legislated through grid codes or market rules and what should be left to markets. To address this issue, some level of harmonization is required to enable DSF (directly or through aggregation) to access the benefits of cross-border trade. This harmonization mainly needs to be reflected in the SOGL, EBGL and CACM as stated in ASSET.
- Enriched functions of the evolving roles of DSOs that add complexity to the distribution grid;
- Balanced proportionality of flexibility type and system requirements.
- Introduce operational regime of digital platforms that are already being tried in different European countries to facilitate flexibility operations in managing the needs of the electrical grid.

For addressing the above, three policy, options are proposed in ASSET based on an adequate level of DSO-TSO coordination and a pathway towards integration of congestion management markets with the wholesale level markets. Depending on the pathway chosen:

- Amendment of existing network codes could be sufficient (Option 1)
- Introduction of new network code could be required (Option 2) or
- Both amendments of existing network codes and introduction of new ones could be needed (Option 3).

The identified pathways are in line with the main insight from the interviewees where all recommendations on the main challenges of operation -including DSF- should be approached under the prism of fixing existing and then development of new codes if needed. More details for the three pathways can be found in ASSET.

Annex

4.3 Factsheets

Use Case 1:

INTERPLAN

INTEgrated opeRation PLANning tool towards the pan-European network

Transforming Grid Operation Planning

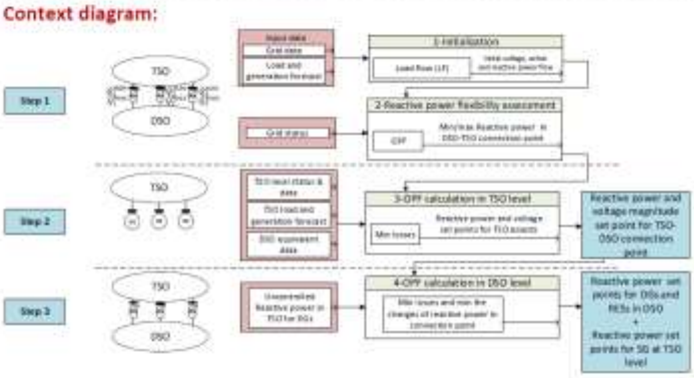
Use Case 1: Coordinated voltage/reactive power control

Objective: Minimizing the deviation from voltage and reactive power set points at TSO-DSO interface as well as minimizing grid losses in both levels.

Network operation planning criteria: Minimising the losses, maximizing the share of RES, assuring voltage stability, optimizing the TSO-DSO interaction, maximizing the DRES/ DG contribution to ancillary services.

Use case solution: Optimized planning (for the next 24 hours) of reactive power distribution at both transmission and distribution levels with a focus on TSO-DSO interface regarding reactive power set points at the connection points provided by the TSO as well as the minimization of grid losses in both levels.

Context diagram:



Description:

Step 1: After performing an initial power flow, a minimum and maximum reactive power flexibility assessment is performed to calculate the resulting flexibilities for the DSO at the TSO-DSO connection points using an OPF.

Step 2: Considering the calculated initial values as well as the possible reactive power flexibilities from Step 1, an OPF at TSO level is performed with the subject of loss minimization. Here, equivalent generators represent the DSO level.

Step 3: The DSO calculates the reactive power set points for the controllable units using an OPF to achieve the calculated set points for reactive power at the connection points. In this way, the losses at the DSO level are also minimized.

Operation challenge:

- Voltage stability

Actors:

- TSO
- DSO

Controllable units:

- Synchronous generators
- DRES and DG

Project duration

1 November 2017 - 31 January 2021

Contact

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This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 773708

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INTERPLAN

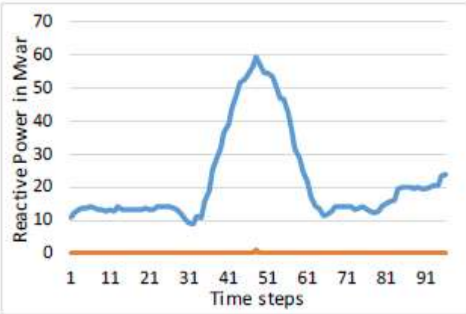
INTEgrated opeRation PLANning tool towards the pan-European network

Transforming Grid Operation Planning

The key results of implementing use case 1 control functions:

Mean quadratic deviation from reactive power targets at TSO and DSO connection points:

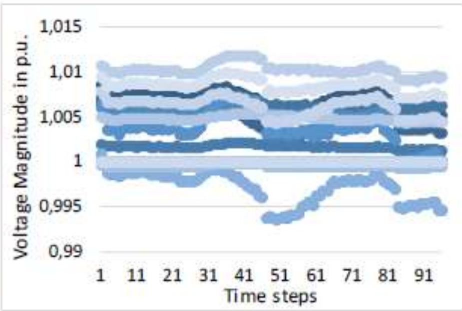
- This diagram presents the mean quadratic deviations from reactive power targets at the TSO and DSO connection points without use case 1 control function (blue curve) and with the presence of control function (orange curve).



- The simulation is performed for the time range for one day with the resolution of 15 Minutes. As the curves show, the mean quadratic deviation regarding the target values for reactive power is close to zero for every time step.

Voltage Quality in TSO and DSO network:

- This diagram presents voltage magnitudes for the 96 different time steps over the busses (represented by the color). Due to the amount of busses in the regarded network, the figure only shows the values for the TSO network.



- The simulation is performed as mentioned above. The values of the voltage magnitudes show that all voltages of the TSO network are within the limits of ± 4-7% of the nominal voltage (according to EN 50160 Standards and VDE-AR-N 4120). Also, the values for the DSO network are within the limits defined there. The values show that the developed and applied control function of UC1 assures the voltage stability in both grids.

Use case developer: Fraunhofer IEE (yannic.harms@iee.fraunhofer.de, lothar.loewer@iee.fraunhofer.de)

INTERPLAN Tool Use Case 1:

Coordinated voltage/reactive power control

Project duration
1 November 2017 - 31 January 2021

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Use Case 2

INTERPLAN

INTEgrated opeRation PLANning tool towards the pan-European network

Transforming Grid Operation Planning

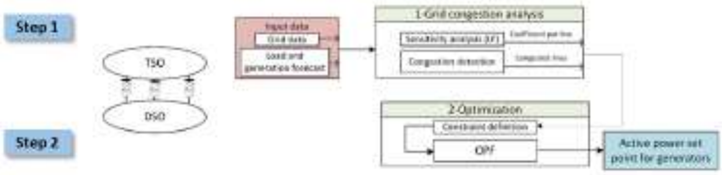
Use Case 2: Grid Congestion Management

Objective: Optimization of the active power variation of flexible resources for solving the congestion issues.

Network operation planning criteria: Mitigating grid congestion, maximizing DG/DRES contribution to ancillary services.

Use case solution: The congestion issues are solved by optimizing the active power variation of flexible resources. In detail, instability events are identified and the optimization function is activated to evaluate the total minimum active power variation to apply to each busbar for their solving.

Context diagram:



Description:

Step1: The TSO detects congestion issues and triggers the congestion management process.

Step2: The active power flexibility assessment per each resource is performed at both TSO and DSO level. This assessment is essential to know the possible active power variation at each busbar to solve the congestion problems detected in step 1. Then a sensitivity analysis is performed to calculate the minimum active power variation at each busbar to solve the detected grid congestion problems at TSO level.

Use case developer: Roberto Ciavarella (roberto.ciavarella@enea.it)

Operation challenge:

- Congestion Management

Actors:

- TSO
- DSO
- Aggregator

Controllable units:

- Synchronous generators
- DRES and DG

Project duration
1 November 2017 - 31 January 2021

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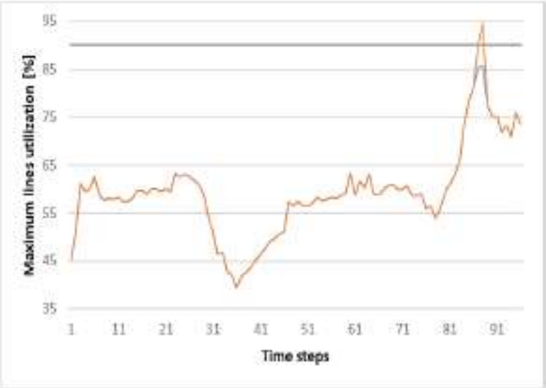
Transforming Grid Operation Planning

The key results of implementing use case 2 control functions:

Congestion Detection

The following diagram shows the maximum line utilization with (blue curve) and without (orange curve) use case 2 control function. This function allows mitigating the congested lines, evaluating the optimal active power set points of distributed resources for ensuring that maximum lines' loading is lesser than the limit value of 90%.



The simulation is performed for the time range of 00:00 to 23:45 with the resolution of fifteen minutes.

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INTERPLAN Tool Use Case 2:

Grid Congestion Management

Project duration
1 November 2017 - 31 January 2021

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This project has received funding from the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 773708

Use Case 3

INTERPLAN

INTEgrated opeRation PLANning tool towards the pan-European network

Transforming Grid Operation Planning

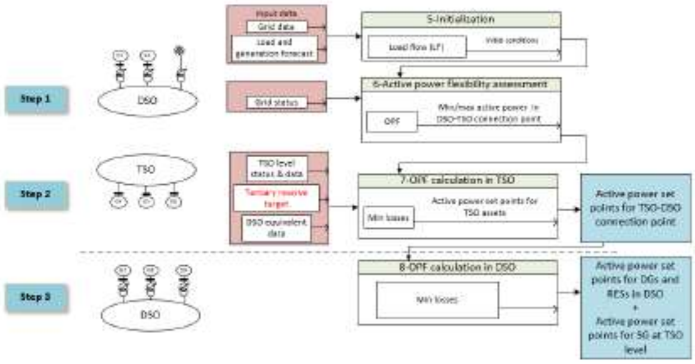
Use Case 3: Provision of frequency tertiary reserve based on coordinated TSO-DSO active power optimization

Objective: Improving the frequency stability through optimised allocation of frequency tertiary reserve.

Network operation planning criteria: Minimising the losses, maximising the share of RES, Optimising the TSO-DSO interaction, maximising the DRES/ DG contribution to ancillary services.

Use case solution: Optimised planning (for the next 24 hours) of active power distribution at both transmission and distribution levels with a focus on TSO-DSO collaboration and by involving as much as possible the flexible RES available at both transmission and distribution levels as well as demand side management.

Context diagram:



Description:

Step1: The DSO, having an equivalent model for transmission network, identifies the maximum and minimum available active power for the points of common coupling.

Step2: Considering the required tertiary reserve for the moment of simulation and having an equivalent model for distribution network, the TSO identifies the active power set points for the points of common coupling and the TSO generation units.

Step3: The DSO with regards to the identified set points from step2, calculates the set points for the remaining controllable units i.e. generators and controllable loads at DSO level through solving multi-objective optimisation problem (minimising the losses, maximising the share of RES, etc.).

Use case developer: Ata Khavari (ata.khavari@der-lab.net)

Operation challenge:

- Frequency stability

Actors:

- TSO
- DSO
- Aggregator

Controllable units:

- Synchronous generators
- DRES and DG
- Flexible loads

Project duration

1 November 2017 - 31 January 2021

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INTERPLAN

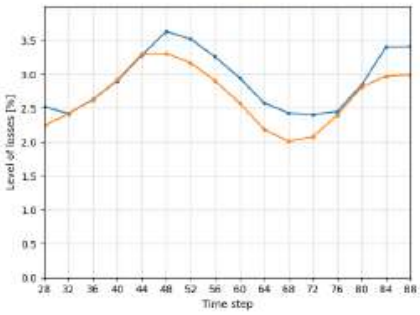
INTEgrated opeRation PLANning tool towards the pan-European network

Transforming Grid Operation Planning

The key results of implementing use case 3 control functions:

Level of losses in transmission and distribution networks:

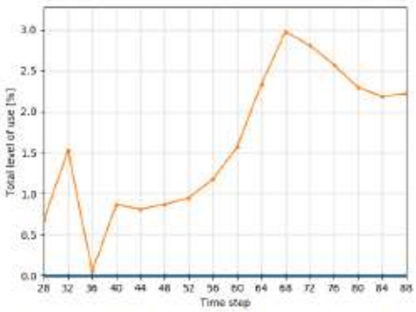
- This diagram presents the level of active power losses without use case 3 control function (blue curve) and with the presence of control function (orange curve).



- The simulation is performed for the time range of 7:00 to 22:00 with the resolution of one hour. As the curves show, in most of the time steps the active power losses are decreased (maximum 0.5%).

Level of distributed RES participation in ancillary services (provision of tertiary reserve):

- This diagram presents the level of distributed RES utilisation in ancillary services without use case 3 control function (blue curve) and with the presence of control function (orange curve).



- The simulation is performed as mentioned above. As the curves show, the use case 3 control function is able to involve the renewable energy sources available in the distribution level in providing tertiary reserve and supporting the TSO in ensuring the frequency stability of the system.

Use case developer: Ata Khavari (ata.khavari@der-lab.net)

INTERPLAN Tool Use Case 3:

Provision of frequency tertiary reserve based on coordinated TSO-DSO active power optimization

Project duration

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Use Case 4:

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Transforming Grid Operation Planning

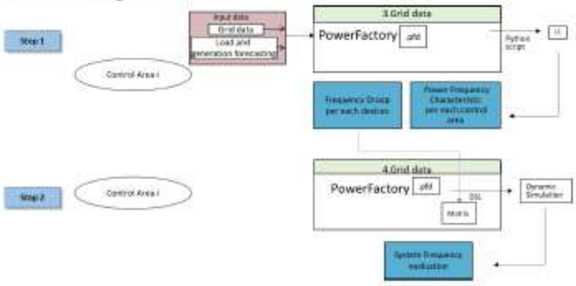
Use Case 4: Fast Frequency Restoration Control

Objective: Improving frequency stability by using local distributed resources integrated in the grid.

Network operation planning criteria: Assuring transient stability, maximizing DG/DRES contribution to ancillary services, Assuring frequency stability.

Use case solution: Identification of instability events in predefined control areas and activation of specific functions to, locally, solve local problems. These functions: (i) solve the total tie-lines active power variation by using the assets in the control area; (ii) evaluate the active power flexibility available at local resources level; (iii) define the power-frequency response per each resource.

Context diagram:



Description:

Step1: Calculate the total power-frequency characteristic per each control area of the power grid under analysis. Thus, based on the asset's flexibility information, the frequency droop per each device is calculated. Calculation of frequency droop per each device is used as input setting for the asset's dynamic models.
Step2: Frequency Droop per each device is systematized under a matrix. A dynamic simulation of an instability event is performed. This is done in order to locate the instability event in the grid and verify the effectiveness of the devices frequency droop calculated at step one. System Frequency is evaluated whereas post-processing is performed offline. The post-processing result is a set of plots and KPIs metrics.

Use case developer: Roberto Ciavarella (roberto.ciavarella@enea.it)

Operation challenge:

- Frequency stability

Actors:

- TSO
- DSO
- Aggregator

Controllable units:

- Synchronous generators
- DRES and DG

Project duration
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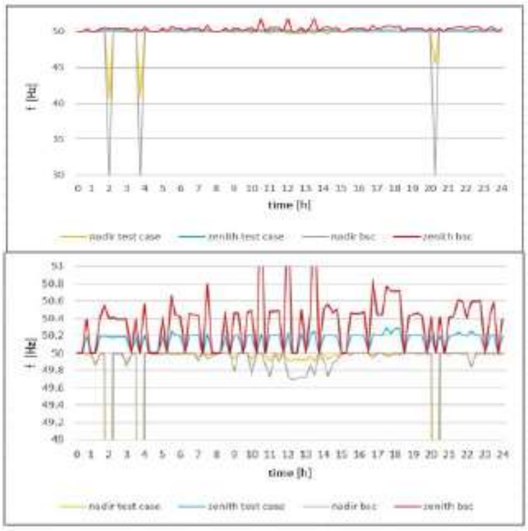
Transforming Grid Operation Planning

The key results of implementing use case 4 control functions:

Frequency restoration control effectiveness

The upper diagram shows frequency minimum and maximum values after a generator/load trip with (yellow and blue curves) and without (grey and red curves) use case 4 control function.



In the lower diagram, a zoom in the interval 49-51 Hz is presented.

- The three most severe cases (f<48 Hz) are the synchronous generator trips. In those cases, the system was unsuccessful in bringing the frequency back to safe operational values due to a lack of frequency support from UC4 (as synchronous generators are not within defined control areas). In the rest of the cases, (where the trip occurred in one of the control areas) UC4 has helped with reducing frequency nadir/zenith.
- The simulation is performed for the time range of 00:00 to 23:45 with the resolution of fifteen minutes.

Use case developer: Roberto Ciavarella (roberto.ciavarella@enea.it)

INTERPLAN Tool Use Case 4:

Fast Frequency Restoration Control

Project duration

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Use Case 5

INTERPLAN

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Transforming Grid Operation Planning

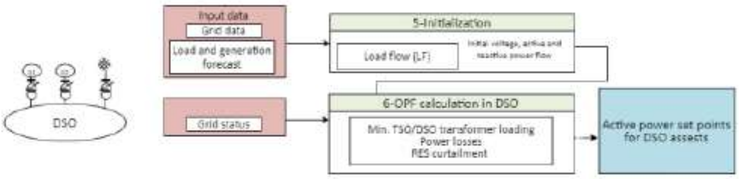
Use Case 5: Power balancing at DSO level

Objective: Minimization of the energy flow between transmission and distribution network by optimal power flows at DSO level.

Network operation planning criteria: Minimizing losses, maximizing share of RES, Optimize TSO/DSO interaction.

Use case solution: For each time step in a chosen time-frame, the algorithm performs multi-objective OPF so that the UC goal is met in the best possible way.

Context diagram:



Description:

Step1: Grid model is initialized in PowerFactory.

Step2: Load flow is performed in order to evaluate the grid state at a given time step.

Step3: OPF is performed to find the best possible solution, considering given objectives and their weights (minimize losses, maximize RES utilization and minimize power exchange with TSO).

Operation challenge:

- Local energy usage

Actors:

- DSO

Controllable units:

- Storage
- RES

Project duration

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Use case developers: Michał Bajor (m.bajor@ien.gda.pl), Anna Wakszyńska (a.wakszynska@ien.gda.pl)

INTERPLAN

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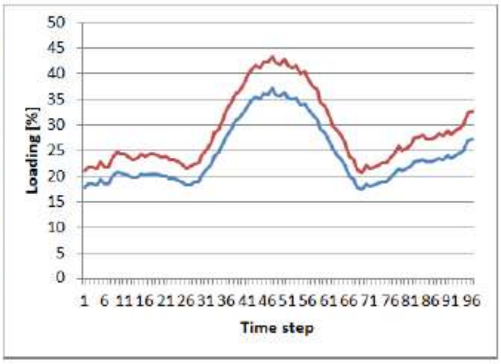
Transforming Grid Operation Planning

The key results of implementing use case 5 control functions:

TSO/DSO transformer loading:

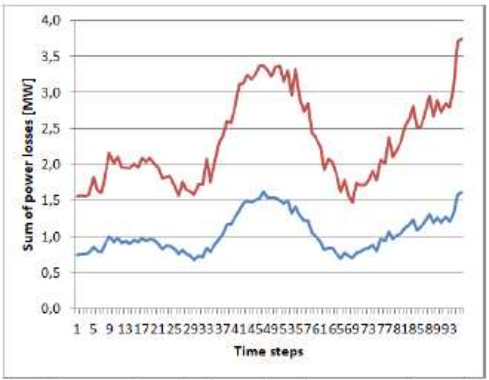
- This diagram presents the level of TSO/DSO transformer loading without use case 5 control function (red curve) and with the presence of control function (blue curve).



- The simulation is performed for the time range of 24h with the resolution of 15 min (96 time steps). As the curves show, in all of the time steps the TSO/DSO transformer loading has decreased.

Power losses:

- This diagram presents the sum of power losses without use case 5 control function (red curve) and with the presence of control function (blue curve).



- The simulation is performed as mentioned above. As the curves show, the use case 5 control function significantly reduces active power losses in the distribution system.

Use case developers: Michał Bajor (m.bajor@ien.gda.pl), Anna Wakszyńska (a.wakszynska@ien.gda.pl)

INTERPLAN Tool Use Case 5:

Power balancing at DSO level

Project duration

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Use Case 6

INTERPLAN

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Transforming Grid Operation Planning

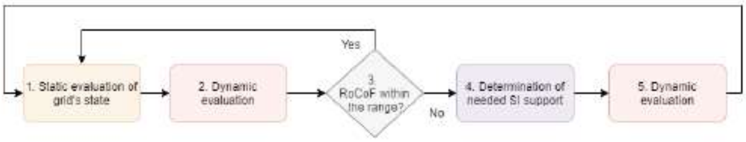
Use Case 6: **Inertia management**

Objective: Maintaining frequency stability in low inertia power system through limiting rate of change of frequency (RoCoF).

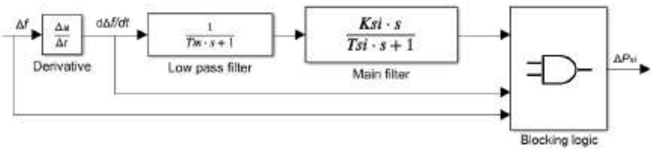
Network operation planning criteria: Assuring frequency stability.

Use case solution: For each time step in the operation planning period, the algorithm dynamically evaluates frequency stability in terms of biggest possible outage (based on forecasted grid state). If the required RoCoF is too high, the algorithm calculates the amount of necessary support in the form of synthetic inertia (SI). For this purpose, also a novel SI controller is proposed.

Use case diagram:



SI controller diagram:



Description:

Step 1: Grid model is initialized and forecasting data together with generation schedule are loaded.
Step 2 & 3: Frequency stability and possible need for additional inertial support are assessed for each step in the whole forecasting time window through a dynamic simulation.
Step 4 & 5: If needed, the synthetic inertia is activated in available units and dynamic simulation is performed in order to evaluate frequency stability with additional SI support.

Operation challenge:

- Frequency stability

Actors:

- TSO
- DSO
- Aggregator

Controllable units:

- Storage

Project duration
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INTERPLAN

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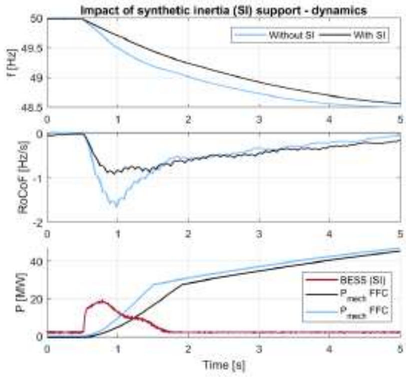
Transforming Grid Operation Planning

The key results of implementing use case 6 control functions:

Dynamic properties of SI control:

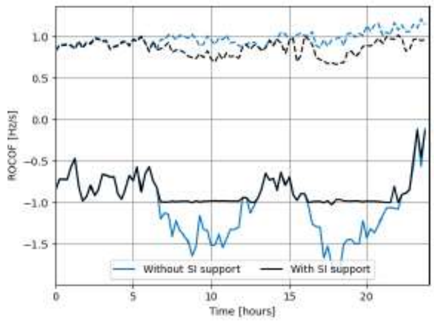
- These plots present the operation of the proposed synthetic inertia controller in response to the generation trip.
- Here, the SI controller is activated in the battery energy storage system (BESS) but in principle, it can operate in most fast-acting power sources.



- Two cases are compared: for the one without SI, high RoCoF can be expected should the generator trip happen. The activation of SI proves to limit RoCoF to the required level of 1 Hz/s. SI response is quick and fast-decaying so it can fill the gap before fast frequency control (FFC) comes into play.

Application of SI to operation planning with focus on inertia management:

- The amount of SI necessary to assure RoCoF limitation can be calculated in the operation planning phase.
- This diagram presents expected worst-case RoCoF values in the day-ahead planning window without and with the calculated SI support.



- The proposed inertia management algorithm informs the operation planner about the necessary amount of SI that should be deployed among available resources capable of providing such a service. This amount is variable in time and can be acquired using typical instruments, e.g. merit order.

INTERPLAN Tool Use Case 6:

Inertia management

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Use Case 7:

INTERPLAN

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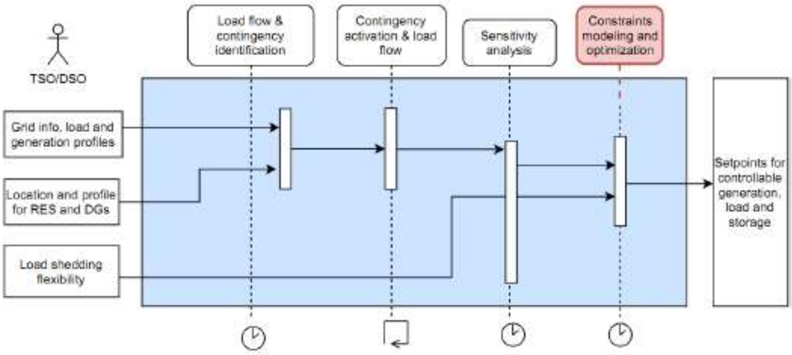
Transforming Grid Operation Planning

Use Case 7: Optimal Energy Interruption Management

Objective: Minimize the cost associated with generator re-dispatch and load interruption for satisfying operational constraints in the post-contingency operational state of the grid.

Network operation planning criteria: Resolving the network constraint violations after a contingency, maximizing DG/DRES contribution to ancillary services and optimal schedule for interruptible loads based on the energy tariffs.

Use case solution: This algorithm resolves the network constraint violations (line congestion, voltage limits) after a contingency by solving an optimization problem in which the active and reactive power of participating generators is re-dispatched and a schedule for energy interruption for loads is obtained with the aim of minimizing the cost of energy interruption and generators re-dispatch.



Description

Step1: A TSO/DSO prepares the grid information (network model), load, generation forecasts and identify a list of credible contingencies.
Step2: For each contingency, load flow is evaluated, and sensitivity analysis is performed. It helps to identify the influence of dispatchable generators and interrupt-able loads on critical lines and buses. This information is used to define the penalty cost terms that assigns less penalty costs to the terminals whose control action can influence more the grid constraint violation. This cost is additional to the cost of generator redispatch and load interruption based on energy tariffs.
Step3: The optimization problem is solved to yield generator & load set-points. This schedule is evaluated for each contingency and can be used offline to prepare network resources. The software can also be used during operation.

Use case developer: Sohail Khan (sohail.khan@ait.ac.at), Sawsan Henein (sawsan.henein@ait.ac.at)

Operation challenge:

- Optimal Energy Interruption Management in Post-Contingency

Actors:

- TSO
- DSO

Controllable units:

- Dispatchable generators
- Interruptible loads

Project duration
1 November 2017 - 31 January 2021

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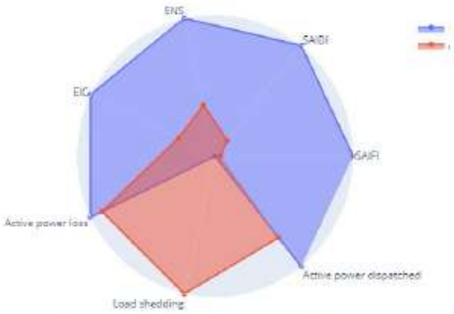
Transforming Grid Operation Planning

The key results of implementing use case 7 control functions:

Comparative analysis of multiple KPIs for each contingency before and after applying control strategy for radial grid:

- This diagram presents the comparative analysis of multiple KPIs before (blue curve) and after (red curve) activation of control functions in radial configuration.



- It can be noticed that reliability indices have reported considerable improvement at the expense of the load shedding and increased dispatch of active power from DGs. The KPIs are averaged over all contingencies and normalized along each axis separately.

Comparative analysis of multiple KPIs for each contingency before and after applying control strategy for meshed configuration:

- This diagram presents the comparative analysis of multiple KPIs before (blue curve) and after (red curve) activation of control functions in meshed configuration.

- It can be noticed that reliability indices have reported considerable improvement at the expense of the load shedding and increased dispatch of active power from DGs. The KPIs are averaged over all contingencies and normalized along each axis separately.

Use case developer: Sohail Khan (sohail.khan@ait.ac.at), Sawsan Henein (sawsan.henein@ait.ac.at)

INTERPLAN Tool Use Case 7:

Optimal Energy Interruption Management

Project duration
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Fact sheet tool:

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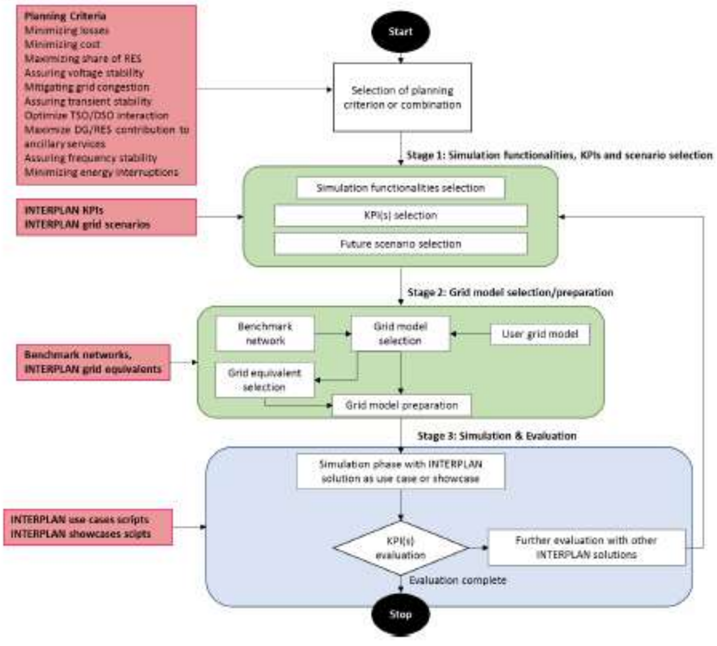
Transforming Grid Operation Planning

INTERPLAN Integrated Operation Planning Tool for the Pan-European Network

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

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 (EVs). 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 figure below represents 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.



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INTERPLAN tool overview

As shown in the figure, the user identified as a TSO or a DSO selects the planning criteria he/she 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

Project duration

1 November 2017 - 31 January 2021

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Assuming 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.

What are the strengths of the INTERPLAN tool?

- **An integrated approach.** It allows dealing with the operation planning of the Pan-European network through an integrated approach. By providing the possibility to investigate all network voltage levels for operational planning purposes, the tool enables integrating the actions made by different stakeholders such as TSOs and DSOs, which are considered as the primary users for the tool. In addition, this integrated approach allows building a bridge between static, long-term planning and considering operational issues by introducing proper control functions in the day-ahead operation planning phase.

- **Simplification.** With the current network operation planning approaches, it is not possible to consider all existing networks (including full models) in an integrated planning tool due to computational limitations, lack of detailed models, etc. Through the intrinsic grid equivalenting methodology and the related grid equivalents library, the tool allows simplifying certain parts of a grid while keeping the relevant characteristics. This grid equivalenting methodology which is applicable to both transmission and distribution levels, can be used to address operational challenges occurring in all network levels.

From the practical point of view:
The INTERPLAN tool can be transformed into 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.

- **Specific and general operational challenges from both TSO and DSO perspective.** Through the control functions embedded within INTERPLAN use cases and showcases, the tool addresses a number of operational challenges of the current and future 2030+ power networks from the perspective of both TSOs and DSOs. On one hand, INTERPLAN use cases address very specific operational challenges that grid operators may face in the presence of high penetration of RES, storage, DR and EVs. On the other hand, INTERPLAN showcases address more general operational challenges that grid operators may typically face for grid operation planning purposes.

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Grid Equivalenting:

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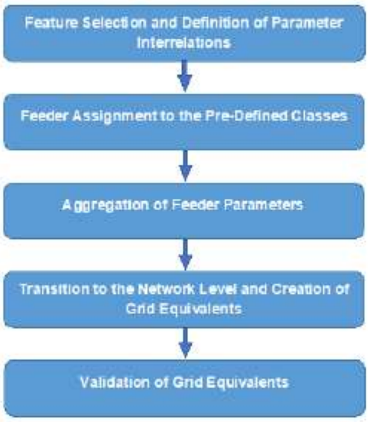
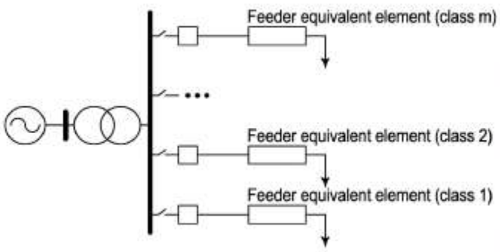
Transforming Grid Operation Planning

Approach for generating grid equivalents

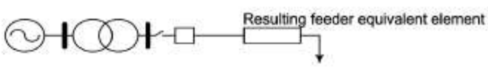
To support the EU power system planning and operation, a more fruitful interaction between DSOs and TSOs is expected, for which grid equivalents representing different parts of electrical networks are required. A fundamental step for this is feeder/ grid clustering, which allows identifying unique grid/ feeder clusters depending on specific network properties. Clustered electrical networks will provide the basis for the creation of a standardized reference grid model, permitting a wide range of simulations while requiring limited data input.



Basic algorithm for generating grid equivalents



Equivalenting of the population of feeder classes



Single equivalent representation

The basic grid equivalent should represent in a simple model the complex grids by only considering basic characteristics like connection node voltages and reactive and active power values. This can be achieved by scaling up of most representative feeders based on grid clustering. Thus, the resulting grid equivalent should look like a small network model with one or more feeders depending on the different identified feeder/network classes.

Type of grid equivalents:

- *Basic Grid Equivalents* – Simple representation of the grid focusing on preserving Voltage, Active and Reactive power characteristics.
- *Advanced Grid Equivalents* – Complex representation considering also different voltage levels and equivalenting different grid areas.
- *Dynamic Grid Equivalents* – Simple or Advanced Grid Equivalents suitable for transient stability studies.

Project duration

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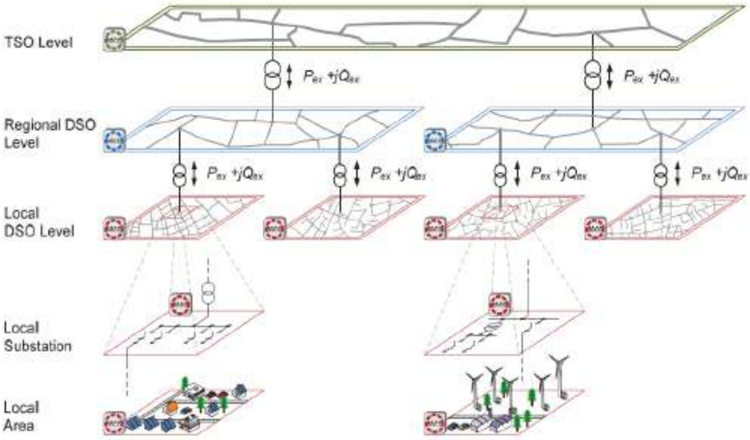
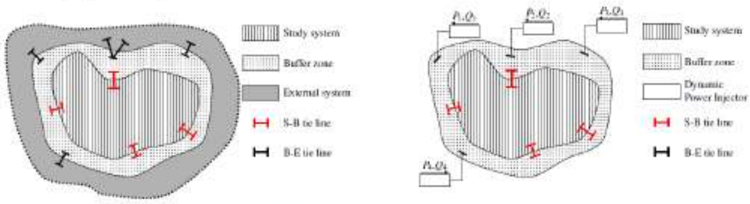
Transforming Grid Operation Planning

The advanced grid equivalents should be a combination of basic grid equivalents considering the topology and different voltage levels. The main idea is to keep as intact as possible the grid transformers parameters of the voltage levels under focus. The next figure shows for what parts of the network grid equivalenting should/could be performed.



Voltage levels used for the advanced grid equivalents

The dynamic grid equivalent consists of dynamic power injectors (DPIs) distributed along the boundary of the study system and emulating the response of the external system to active power imbalance and frequency excursions. The equivalent focuses on the global of rotor oscillation, which is the well-damped oscillatory mode with the lowest frequency present in all machine speed responses. The figure below represents and abstract illustration of the reduction of a large power system.



(a) Unreduced system divided into a study system, buffer zone and external system.

(b) Reduced system with external system replaced by DPIs.

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INTERPLAN Tool
Grid Equivalents:

Provision of grid-equivalents covering all voltage levels to be incorporated in the operation planning and semi-dynamic simulations environment.

Project duration
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4.4 List of Figures