Enhanced Operation Planning Tool for the EU grid Addressing the Emerging Technologies

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1. Introduction

The goal of the INTERPLAN project is to provide an INTEgrated opeRation PLANning tool towards the pan-European network, to support the European Union in reaching the expected low-carbon targets, while maintaining the network security. A methodology for proper representation of a "clustered" model of the pan-European network will be provided, with the aim to generate grid equivalents as a growing library able to cover all relevant system connectivity possibilities occurring in the real grid, by addressing operational issues at all network levels (transmission, distribution and TSOs-DSOs interfaces). In this perspective, the chosen top-down approach will lead to an "integrated" tool, both in terms of voltage levels, going from high voltage down to low voltage up to end user, and in terms of building a bridge between static, long-term planning and considering operational issues by introducing controllers in the operation planning. Proper cluster and interface controllers will be developed to intervene in presence of criticalities, by exploiting the flexibility potentials throughout the grid.

The regulations and policies applied in every country of the consortium which influence the implementation of the emerging technologies into the grid are compiled as a reference and as an assisting tool in the future steps of the project. Using this information, shortcomings to be addressed by INTERPLAN have been identified.

In addition, a list of the tools, models and scenarios for interconnecting the emerging technologies to the grid are also presented and detailed. Finally, the limitations and criticalities of these tools and models are identified and documented.

2. Methodology/Mind Map

The basic INTERPLAN idea which relies on covering a wider range of possible system connectivity and in parallel addressing existing interconnectivity issues, requires a thorough assessment by each participant country in terms of generation, load, transmission, balancing data, TSOs – DSOs interactions, and an overview of the existing grid codes. Therefore, the first phase of the work will focus on a more in-depth analysis of existing projects and studies linked to the above cited themes. The exploitation, in particular, will be oriented to identify more significant scenarios for the later definition of use cases and clustering methodology (grid equivalenting). The choice of use cases will be obviously defined by scenarios analysis of the European electricity grids and should properly represent the actual cases of the current electric grids for each analyzed voltage level.

The “grid equivalenting” term, which is conceptually the successive phase of the work, is the process of generating a grid equivalent model encompassing a large part of network substituted by a smaller counterpart reflecting the same dynamic properties. To this aim, the network models of previous use cases will be designed in a numerical power system simulation environment. Following that, a clustering methodology for transmission and distribution systems up to the end user level will be identified, and a detailed approach for generating grid equivalents will be developed for different use cases. At the same time, several key questions will be answered:

- What is the maximum level of Renewable Energy Sources (RES)/storage/demand response/etc. that still can be neglected whilst constructing the equivalent (the averaging effect) taking into consideration different operational scenarios, challenges and phenomena?
- What impact do they have on the equivalent characteristics and how to consider them in the equivalent model in a way that it is accurate and representative?
- Which parameters of the flexibility resources are the most valuable and critical from the TSO perspective?

The focus in this essence is developing a functional representation of the set of all flexibility resources integrated in the network, as seen from the transmission (TSOs) and transmission-distribution (TSOs-DSOs) interface point of view. This will enable to include them in the operation planning process in order to utilize them more effectively and efficiently, and therefore facilitating and incentivizing their subsequent deployment.

To assess the operational planning aspects, key decisions regarding planning criteria/functionalities (e.g., maximizing RES share in generation portfolio in secure manner) will be taken into account for each use case. Among the planning criteria analyzed above, minimization of the costs will also be taken into account with the objective of minimizing the cost of power dispatch based on operating costs (e.g. cost functions of generating units) and on tariff systems for external grids. The application of the selected criteria to previous use cases will allow the deployment of a number of significant showcases.

Semi-dynamic time-domain simulations of grid equivalents for each showcase will provide the network dynamic behavior, by identifying eventual operational problems and challenges (e.g. lines congestion). In fact, semi-dynamic simulations are particularly suitable for planning and analyzing studies in INTERPLAN project, where long term load and generation profiles are defined in parallel with multiple contingency scenarios in correspondence of simulation periods, ranging from hours up to years with user-defined time step sizes between each simulation. A typical example of a semi-dynamic time-domain simulation is shown in Figure 1, where it demonstrates the operating principle and goal of such a dynamic simulation.

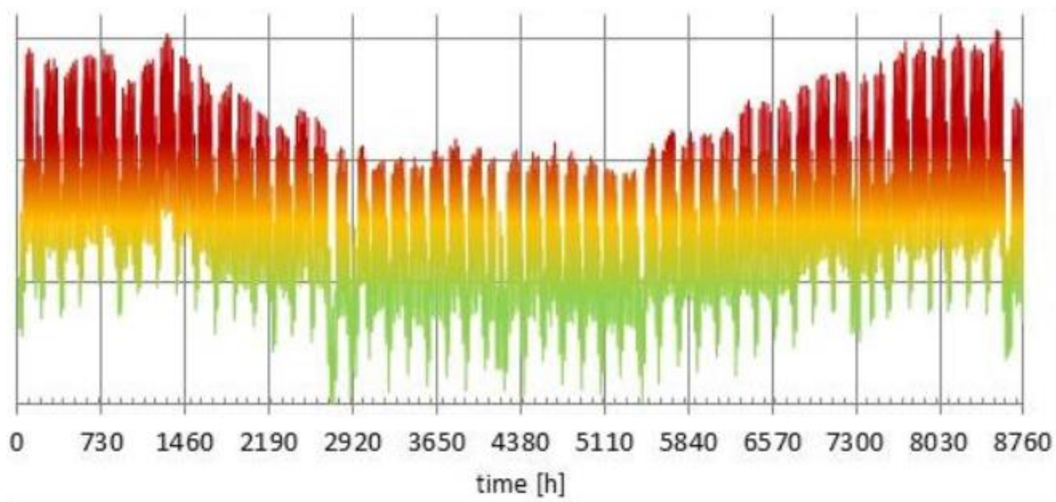

Figure 1: Load profile over the course of 8760 hours (= 1 year) (y-axis dimension is not important in this case since the emphasis is on the profile fluctuation over a year)

The post-processing or parallel-processing of the results will allow to identify operational problems to be solved by developing new control system strategies.

These latter will be designed in order to apply adequate intervention measures through the appropriate control parameters such as storage, demand response and aggregation through cluster and interface controllers. The relationships between key features of the project are reported in the MindMap in Figure 2. Figure 3 shows the relationships between operation planning inputs and INTERPLAN tool components.

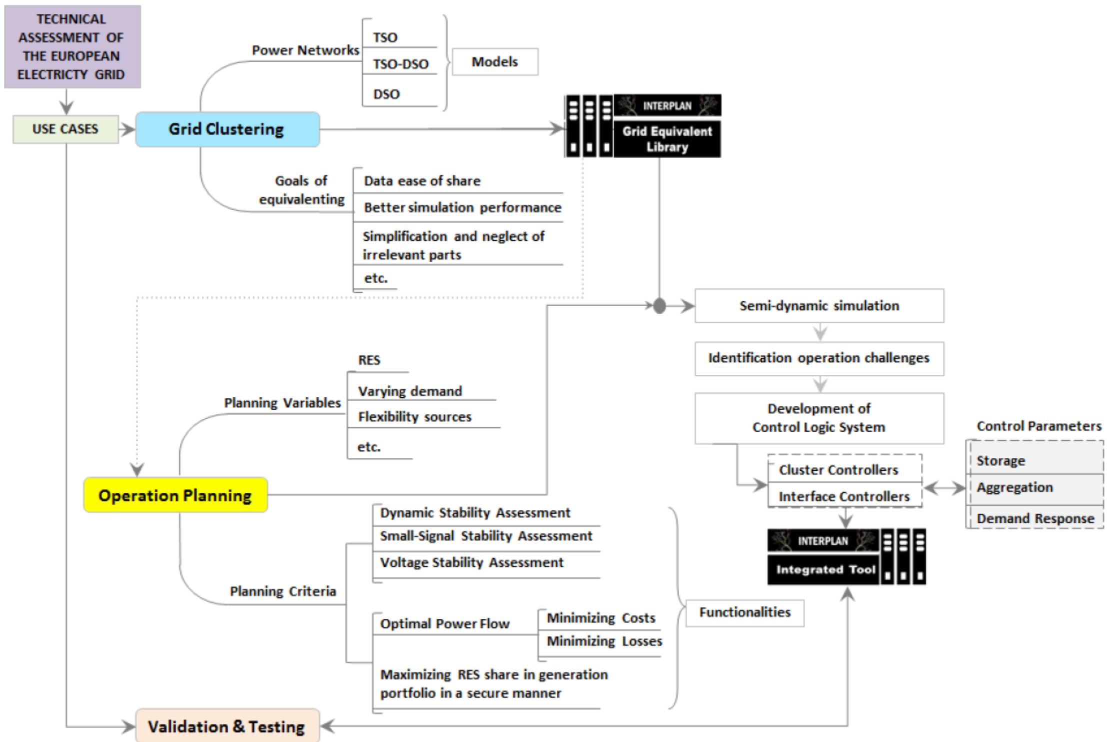

Figure 2: INTERPLAN MindMap

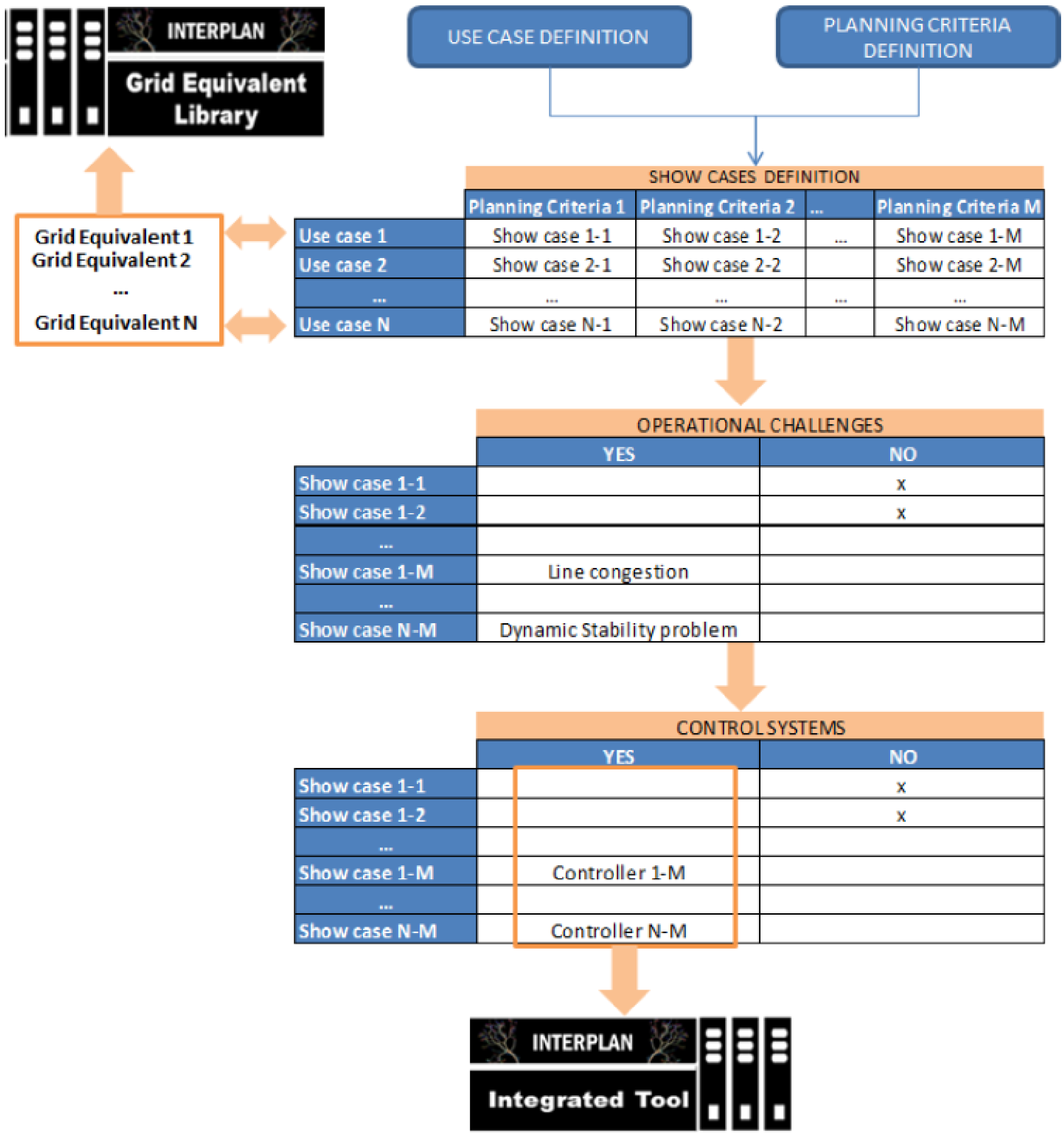

Figure 3: Relationships between operation planning inputs and INTERPLAN tool components

Finally, a validation process will be applied through a numerical simulation environment, to prove and confirm the validity of the proposed concept. In more details, static and dynamic analyses will be led in a laboratory environment, aiming to demonstrate the effectiveness of the proposed innovative tool (e.g., ability to properly address congestion challenges between interfaces of TSOs-DSOs or to apply adequate intervention measures). The validation process in particular is not the final phase of the work, but is a permanent phase, which will allow modification and improvement of the developed tool and dynamic equivalent models designed in an earlier stage of the work.

3. Country assessment

A template has been created to be completed by the countries of the consortium, in order to produce a country-based assessment. The partners who were involved in completing this template were UCY, ENEA, AIT, FRAUNHOFER and IEn. The template allowed the analysis of the current practices in all countries of the consortium through the prevailing grid rules and enacted regulations aiming to:

- Identify adapted policies in handling the three main constituents of the emerging technologies that promise to play a leading role in the years ahead, which are intermittent RES generation, storage of all technologies including EVs and flexible demand response (DR).
- Qualify shortcomings in current practices that need to be addressed in developing and operating the emerging grids.
- Identify responding practices that lead the way to the adoption of the emerging technologies referred to above, and how these can be extrapolated and adapted to play a wider role in the scenarios to be developed under INTERPLAN.

The information from each template was analyzed to produce a single document representing all the countries of the consortium regarding:

- Regulations.
- Policies-Codes.
- Shortcomings required to be addressed by INTERPLAN.
- Responding National Practices that are worthy of picking up to extend and replicate related to the following technologies:
  - Intermittent Renewable Energy Sources;
  - Storage including Electric Vehicles, heat pump solutions for heating and cooling
  - Flexible Demand Response including Electric vehicles, heat pump solutions for heating and cooling, hot water and so on.

In addition, each country of the consortium provided a list of projects and a brief description of them which are in progress and address issues relevant to INTERPLAN and the three technology developments mentioned above.

4. Use Cases (Tools or Functionalities)

The identified emerging technologies that are going to be found in abundance in the integrated grid in the years ahead, which are distributed RES, storage, EVs and DR, call upon enhanced functionalities requiring system means to utilize efficiently but also exhaustive use cases through which the grid needs will be validated to safeguard the security and the quality of energy supply. The list below gives a good subset of the use cases to be implemented in the INTERPLAN project, aiming to test the developed solutions and will be further elaborated in WP3 to form the basis for WP4 and WP5. These use cases are addressed in the content of this task, since an initial indication of the expectations is crucial for identifying the targeted limitations and shortcomings of the present models and analytical tools.

- UC1: Coordinated grid voltage control
- UC2: Grid congestion management
- UC3: Frequency stability – Tertiary control
- UC4: Frequency stability – Fast restoration
- UC5: Optimizing the power balancing at DSO level to minimize the energy flow between transmission and distribution
- UC6: Increase resilience of the interconnected grid with effective use of local resources
- UC7: Inertialess grid potential offering high efficiency, security and quality of supply

- UC8: Reactive power setpoints at TSO/DSO interface
- UC9: Impact of coordinated voltage control algorithms on the system reliability

5. Scenarios to be investigated

It has been aimed to identify the limitations and shortcomings of current regulations, models and operational tools in handling efficiently the emerging technologies RES, storage, EVs including smart charging and DR. To help identifying these limitations and shortcomings, it is necessary to have an initial impression of the targeted scenarios in the evolution of the integrated grid for the years 2030 / 2040 and beyond. The main scenarios and the relevant projects that involve these types of scenarios are listed below:

➢ 100% RES - Covered by E-Highway, ELECTRA1 and GRID4EU

This scenario relies only on RES, thus nuclear and fossil energy generation are excluded. High GDP, high electrification and high energy efficiency are assumed. Storage technologies and demand side management are widespread.

➢ Distributed generation - E-Highway, 2018 ENTSO-E TYNDP, All EUCO, ELECTRA, GridTech and GRID4EU

These scenarios place prosumers at the centre. They represent a more de-centralised development with focus on end user-technologies. Smart technology and dual fuel appliances, such as hybrid heat pumps, allow consumers to switch energy depending on market conditions. Electric vehicles see their highest penetration with PV and batteries widespread in buildings. These developments lead to high levels of demand side response available.

Considerations on how the electricity grid will look like in 2030 / 2040: Small-scale generation technologies costs will rapidly decline. Technologies such as solar will offer a non-subsidized option for "prosumer" in most parts of Europe. Major advances in batteries will enable "prosumers" to balance their own electricity consumption within a day. Nuclear mostly will depend on country specific policies. Small-scale generation will challenge large-scale power generation, pressurizing the profitability of traditional power plants. System balance will be maintained through a centralized mechanism that retains enough peaking capacity. District heating CHPs will be suitable for both heating and electricity balance. Electricity demand flexibility will substantially increase, both in residential and industrial solutions, by helping electric power adequacy. Yearly electricity demand will increase in heating (e.g., heat pumps) and transports (e.g., EVs) sectors. The overall electricity demand growth will reduce in the residential sector due to the "prosumer" behavior.
Demand will respond well to market price, and the peak electricity demand will reduce.

➢ Distributed generation description of GRID4EU

Solutions related to voltage and load control are beneficial resources to increase network hosting capacity in European distribution grids. The advanced control of On Load Tap Changer at MV level in the Italian Demonstrator and at MV/LV level in the French Demonstrator is a major resource for increasing the Hosting Capacity (even the most beneficial one tested in the Italian Demonstrator where it has been increased by up to more than 50% in a specific experimentation). But, it is useful to highlight that an OLTC only acts on voltage constraints, not on power constraints. Also, in case of voltage imbalances due to the presence of “active” (i.e. Pgen >> Load) and “passive” (i.e. Load >> Pgen) MV feeders connected to the same HV/ MV substation’s bus-bar, the action of the On Load Tap Changer can be ineffective thus,

requiring the introduction of the control of DERs connected along the feeders (e.g. distributed generators, storage systems, etc.).
The Scalability and Replicability Analyses performed in GRID4EU also point out that the interaction of Distributed Generation (DG) and demand curves is a key aspect to increase network hosting capacity. While this aspect depends mainly on the type of consumers and Distributed Generation technology, energy storage and flexible demand can help increase network hosting capacity.

For higher grid resiliency, it is technically feasible to operate the grid in islanding mode during more than 4 hours, with and also without rotating machines, while complying with strong requirements in terms of continuity of supply.

➢ Global Climate Action / Integrated grid: E-Highway, 2018 ENTSO-E TYNDP, EUCO+40, ELECTRA, GRID4EU

These scenarios represent a global effort towards full speed decarbonization. The emphasis is on large-scale renewables and even nuclear in the power sector. Residential and commercial heat, become more electrified leading to a steady decline of gas demand in this sector. Decarbonization of transportation is achieved through both electric and gas vehicle growth. Energy efficiency measures affect all sectors. Renewable gases see their strongest development within this scenario.

Considerations on how the electricity grid will look like in 2040: A CO2 market price will provide the correct market signals that trigger investments in low-carbon power generation technologies and for flexibility services. A technology-neutral framework will be established, which will support investment in RES. Gas-fired units will provide flexibility needed within the power market, helping facilitate intermittent RES within the market. Nuclear will mostly depend on country specific policies. System adequacy will be driven by price signals, which allows market-based investments in peaking power plants to be made. The impact of electrification will be that demand for electricity use in private and small commercial transportation sector will increase. Demand response in both industrial and residential sectors will increase. Increased automation of things and the internet will give consumers the option to move their demand to the lower-priced hours. Demand flexibility will be a key factor ensuring system adequacy to its ability to shift demand peaks. Yearly electricity demand will increase in various sectors. The overall electricity demand growth will be limited by increasing energy efficiency.

➢ Global Climate Action / Integrated grid - Vision 2050 description from GRID4EU

Energy systems are systems of systems, including the electricity systems, the gas systems, the liquid fuel systems, the heating and cooling systems as well as all other systems. The pan-European energy system is a system of energy systems, with connections from cross-border to local level.

In 2050, the impact of the European energy systems on the climate is almost fully tackled. A combination of climate protection measures, including technology deployment for energy generation, storage and conversion and operational procedures help mitigate global and local environmental impacts, making sure that they offset the effects of increasing complexity of the energy systems.
Innovative public policies ensure social participation. They include energy savings and energy efficiency measures, supported by up-to-date communication media. The public is informed

through massive communication that the costs associated to the energy transition are efficient at mitigating environmental impacts and satisfying its needs. Citizens participate actively in the energy transition.
By 2050, the use of fossil fuels is very low for any energy use. Use of crude oil for all domestic, industrial and mobility needs is low thanks to substitution of crude oil with biomass and other renewable energy sources. This has resulted in low-carbon energy systems, even CO2-neutral electricity system and liquid fuels. A low carbon pan-European energy system paves the way for a fully decarbonized and circular European economy beyond 2050.

By 2050 energy markets will operate capable of storing or converting excess power from renewable generation (mainly wind and solar). Energy stored in batteries (stationary or through electric vehicles) is used to shift energy demand during the day. Energy stored in the form of gas is used weekly to a seasonal basis for shifting excess of energy (such as in summer due to PV production) to those periods where more energy is needed (winter in many parts of Europe). Excess electrical energy is converted to CO2-neutral Gas in summer and converted back in winter.
Retail markets are fully integrated with local and wholesale markets. Prosumers' willingness to provide flexibility is achieved by adequate market signals and innovative services guaranteeing a high level of comfort, by high power quality both in terms of satisfying norms (e.g. voltage and frequency within upper and lower limits) and over time (e.g. no blackouts, fast restoration after blackout). Prosumers of any size can access market offers to sell energy or power and to satisfy their needs via communication and internet services. These ICT-based services, which can be integrated with other information services, not directly related to energy, are also used to provide dynamic information (price, quality, state of the system, incentives for energy systems-friendly actions, etc.) to the prosumers for any of their energy related needs, be it selling or buying energy.

In 2050, Europe satisfies all energy needs utilizing only energy sources located within Europe. This means Europe does not rely on fuel and raw materials from outside Europe. This is achieved by avoiding imports of primary fuels, such as gas, liquid fuels and renewable energies from outside of Europe. To that purpose, a fully circular, carbon-free economy has been designed - in the long run and beyond 2050 - for the energy systems with all sources available in Europe.

6. Limitations and Shortcomings

The country-based analysis has shown that countries address adequately a variety of factors, in terms of regulations policies, and codes of the installation and operation of RES systems. However, storage and DR are issues that are still not adequately covered via regulations, policies and codes, and in some countries, they are even non-existent. Modelling and system tools for these technologies are not readily available and hence operators may have difficulties to plan and operate the active network that is emerging and growing, in an efficient and optimal way. These generate shortcomings that call for urgent attention.

What conclusions do we drive as shortcomings of our industry based on the country assessments?

From the detailed analysis presented in the previous sections, the following shortcomings transpire that need to be addressed through INTERPLAN and tested using exhaustive scenarios and use cases. A sample is given in this work, but these are needed to be further enriched in a later stage.

Intermittent RES

The installation of intermittent RES generators at the end of long radial lines or in less developed parts of the power system can cause a voltage violation of the allowable voltage variation envelope that defines the operational limits of the grid due to variation in generation over the time of the day or depending on area cloudiness. The voltage limits in LV networks and MV networks vary and a compensation is required to meet the voltage levels. The ability to maintain the voltage levels in the grid is combined with reactive power controllers and power generation curtailment that should be enforced only in extreme cases.

Lack of observability for distributed RES in planning and operational practices

The evolution of the active grids with distributed RES is not simulated correctly in the planning and operational practices of operators and hence lack in effective solutions for managing them. The aggregated effects of distributed RES are not taken into consideration due to lack of appropriate models and analytical tools.

Advanced features of power electronics in inverters are not fully utilized

The operational benefits of the advanced features of power electronics in inverters and similar connecting apparatus are not utilized by operators in mitigating the negative effects of intermittent generating systems due to lack of models and analytical tools. The aggregated effect of the provided features is not taken into consideration when planning or operating the system leading to underutilization of costly infrastructure.

Storage

Storage in Member States has entered the energy mix and it is used generally as flexible demand and partly as an ancillary service for frequency control. More, recently storage is used as support to intermittent RES for improved load profile of prosumers and other industrial and commercial loads. Storage is to some extend covered by Grid Rules and Market Rules of some of the Member States covering the above referred applications. In all Member States storage is addressed individually as a technology in support of specific needs of the system or end users and its complementary attributes have not been taken up yet. Moreover, the specific attributes and characteristics of EVs and heat pumps capable of responding in system terms as active storage have not been considered or addressed in any capacity. Successful demonstration projects have been conducted and knowledge has grown but commercialization is still behind calling for developments in a lot of

Similarly, it is true to say that, irrespective of this gradual growth in use, none of the Member States has developed models and / or operational tools for effective planning and operation of the integrated grid with storage being an active component.

The aggregated benefits of storage systems with EVs and heat pumps are not used

From the countries' practices, the aggregated benefits of storage, EVs and heat pumps are underutilized in efficiently complimenting the needs of intermittent RES due to lack of adequate models and analytical tools. Optimal planning of the systems requires such analysis through accurate modelling of the active components of the interconnected system.

Storage as a commodity for ancillary services to the system

The countries' practices and the lack of regulation and grid rules in Cyprus and elsewhere indicate that storage is underutilized in the interconnected grid. The versatility of storage systems with the varied services that they can offer in managing frequency, voltage, harmonics and other system quality issues are not taken up by operators due to lack of models and analytical tools to assist operational and planning practices.

Optimal use of storage and effecting siting

Storage can be sited behind the meter, distributed in substations or centrally. It can be a combination of DC connected and AC connected, a combination of standalone as compared to aggregated with EVs and heat pumps. Where it is highly system dependent and for this reason detailed models and analytical tools are required to optimally design the systems of tomorrow. This is the reason why we lack decisions and policies in this direction as indicated by the national investigations above and it is an identified shortcoming that INTERPLAN should address.

Flexible Demand Response

In Poland, TSO assumes utilization of demand response as a regular means for balancing purposes, however there is no standard model allowing for incorporation of the methods used by the TSO to acquire the DR service. The same applies for the aggregator model who incorporates many loads in the system and can share reduction order differently amongst its service providers.

Demand Response in support of system needs

The practices in Poland and the lack of action in the rest of the countries in harvesting the benefits of demand response for managing the needs of the system due to the aggravating effect of intermittent generation but also due to the advanced capabilities of the system since going smart is the result of lack of models and analytical tools that can reveal the huge benefits of this embedded system possibility. DR can take various forms with evolving technologies, but these will take the form that is beneficial when the worth is proven through effective analysis. Operators and system planners can learn to utilize this huge benefit and offer to the system stability and growth by using efficiently the inherent strength of demand as required without violating comfort and needs.

Demand Response complementary to storage for aggregated support to RES

The investigation carried out in the countries of the consortium has revealed that there is a static approach to the distribution grid meaning that the technologies that are matured to offer services to the integrated grid in meeting the targeted low carbon economy are not dynamically present in the plans of operators and planners due to lack of models and analytical tools that will allow them to accurately analyze and operate this active distribution grid.

Demand Response in support for the paradigm shift to load follows generation

From the analysis done it is seen that there is interest to use DR, storage, EVs and heat pumps as acting in an aggregated and coordinated system dynamic component capable of managing the intermittent generation and avoiding curtailment and sustained bad quality of system characteristics. To achieve this accurate models and analytical tools are required capable of accurately analyzing and operating the system for the benefit of all connected users. This will allow technologies to develop further and system solutions to be pursuit that will offer optimal solutions at minimum infrastructure cost.

7. Discussion and Conclusions

The low carbon legislative package that is currently being discussed by the various European Institutions is addressing all issues related to high RES penetration, storage (including EVs) and Demand Response that characterizes the evolution of the electrical grid into an active integrated grid that empowers end users with appropriate tools and means to effectively manage their resources and needs. From the investigation carried out by the consortium through this work, it is evident that:

- Countries have adequately addressed issues related to RES penetration including utilization of the advanced features of inverters / power electronics but still lacking in models and analytical / operational tools that will facilitate system planning and operation at a responsive and reliable level.
- Countries have done little in addressing regulatory and codes needs of storage and DR requiring major legislative procedures to respond to the demanding requirements of the low carbon package. As far as models and analytical / operational tools are concerned the situation is well behind treating the grid as still non-active on the Distribution and radial in nature with central control all the way.

The above limitations have been elaborated in the sections above together with identified shortcomings that the INTERPLAN project should address. These shortcomings will be tackled in later stages of the project and validated using an extensive list of scenarios and use cases. Initial lists of use cases and scenarios have been presented in this work but require to be finalized and further elaborated.

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