INNOVATIVE ELECTRICITY NETWORK OPERATION PLANNING TOOL FOR TSOs AND DSOs

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ABSTRACT

This paper presents an overview of the results obtained during the first year of the INTERPLAN project, which aims to develop an integrated network operation planning tool to support the EU in reaching the expected low-carbon targets while preserving network security and reliability. The integrated tool means in terms of voltage levels, going from high voltage down to low voltage levels, and in terms of building a bridge between static, long-term planning and considering operational issues by introducing controllers in the operation planning.

INTRODUCTION

Moving towards a pan-European electricity network with diverse energy systems and emerging technologies needs novel solutions to support network operation planning in order to ensure the security of supply.

In the H2020 INTERPLAN project (Nov.2017-Nov.2020), an integrated network operation planning tool is developed to support the EU in reaching the expected low-carbon targets while maintaining network security and reliability. Integrated tool means in terms of voltage levels, going from high voltage down to low voltage levels, and in terms of building a bridge between static, long-term planning and considering operational issues by introducing controllers in the operation planning. The tool consists of a library of grid equivalents and controllers, which based on semi-dynamic and dynamic simulations, will allow the user to identify the possible challenges (such as congestion in TSO-DSO interface) in operating the complex ongoing electricity grid and accordingly apply the needed intervention measures. In order to prepare the tool for planning the operation of the future EU grid with a variety of emerging technologies, aspects like maximising renewables share in generation, minimising the power losses and costs throughout the grid and involving DSOs in the power balancing process are taken into account.

A thorough analysis on existing grid codes and regulations at European and National levels is carried out in the project. Current shortcomings to integration of emerging technologies and services, such as renewables, storages, electric vehicles and demand response (DR), as well as the associated best practices are identified. Furthermore, the developments achieved through the project are transformed into policy requirements to be addressed to the regulators and grid operators for possible amendments to the current grid codes.

Based on the identified shortcomings/limitations and practices, use cases (UC) and corresponding showcases for dynamic/semi-dynamic simulations are developed. The use cases address the main challenges for grid operation planning by covering topics like TSO-DSO coordinated active/reactive power control, optimal generation schedule of DER for grid congestion and inertia management. Once different use cases are composed and future EU grid scenarios are identified, a series of showcases for the integrated tool are developed, which address issues such as resiliency of the interconnected grid with effective use of local distributed energy resources.

In the further stages of the project, a methodology for a proper representation of a clustered model of the pan-European network will be developed with the aim to generate grid equivalents able to reflect all relevant system connectivity possibilities occurring in the real grid and addressing operational issues at all network levels, with a key focus on TSO-DSO interactions. Then, a set of controllers will be developed which will allow to identify the operation challenges occurring in complex ongoing electricity grid and accordingly apply the needed intervention measures.

CURRENT REGULATIONS AND GRID CODES

A central role of INTERPLAN project is the in-depth technical and regulatory analysis of the European electricity grid. This translates into the technical assessment of the state-of-the-art of national and European technical practices and regulations aiming to identify possible steps capable of providing an integrated operation planning tool for the implementation of new control and operation approaches at all network levels. This analysis aims to quantify the basis for defining significant use cases and adaptive clustering methods that can facilitate the INTERPLAN targeted operation planning objectives. At the end of the project, the developments achieved will be transformed into policy requirements to be addressed to the regulators and the grid operators for possible amendments to the current grid codes.

In the analysis of existing grid codes and regulations at European and National levels, limitations and criticalities for interconnecting the emerging technologies (intermittent RES, storage of all technologies and flexible demand response) were identified. The analysis showed that countries address adequately the installation and operation of RES systems in terms of regulations, policies and codes. However, storage and DR are issues that are still not covered adequately in some countries, they are non-existent. For all three technologies, modelling and system tools are not available and hence, operators do not have the means to plan and operate the active network that is emerging and growing in an efficient and optimal way. These issues create shortcomings that call for urgent attention, such as lack of observability for distributed RES in planning and operational practices, and lack of models allowing effective use of distributed energy resources (DER) by TSOs [1].

FUTURE EUROPEAN GRID SCENARIOS

INTERPLAN identified suitable scenarios where the future challenges of the Pan-European network and rising technologies are depicted and addressed in order to meet the 2050 goals of the European Union. As a matter of fact, it is challenging to bring together different developed and presented scenarios from different institutions in a common ground. However, INTERPLAN came up with 4 different scenarios (mainly based on e-Highway2050 outcome [2]) for the future European energy grid with time horizons span to 2030 and 2050, which include different perspectives of development from small-scale to large-scale perspective, as well as from centralized to decentralized, from conventional generation to asynchronously connected renewable energy sources, and finally from weak policies to strong policies, inter alia [3]. These four scenarios are entitled as big and market, small and local, large scale RES, and 100% RES, which are fully described in [3]. In the following, the scenario, small and local, which is mainly focused by the project is introduced.

Small and Local: In this scenario, the global community has not succeeded in reaching a solid agreement for climate mitigation. Yet, Europe is fully committed to meet the targeted 80-95% GHG reduction. The European member states have chosen a bottom-up strategy, mainly based on small-scale local solutions to obtain the target. Common agreements and rules for transnational initiatives regarding the operation of an internal EU market, EU wide security of supply and coordinated use of interconnectors for transnational energy exchanges do not exist or defined yet. The focus here, is rather on local solutions dealing with decentralized generation and storage, as well as on smart grid solutions at transmission and mainly on distribution level.

Focus on deployment of decentralized storage and RES solutions is observed, including combined heat power (CHP) and Biomass, while nuclear and Carbon capture and storage (CCS) are not considered as potential options to reach the GHG emission reduction target. The recorded public attitude towards the deployment of local decentralized RES technologies is positive embraced in the EU.

A considerable degree of electrification of transport, heating and industry is realized mainly at the decentralized (small scale) level. There is a corresponding high focus on the deployment of energy efficient solutions, including demand side management (DSM) and flexibility of EV use.

USE CASES AND SHOWCASES FOR THE OPERATION PLANNING TOOL

INTERPLAN use cases [3] look beyond the current regulations and grid codes, and propose solutions in order to face the challenges that high shares of technologies like RES, storage and DR will implicate for operation planning of the future EU grid, and as it was observed, the current grid codes and practices are not able yet to adequately address them. In case the proposed solutions will be evaluated positively in the simulation scenarios planned in the later stages of the project, they will be recommended for possible amendments to grid codes and European regulations.

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

Use Case 1: Coordinated voltage/reactive power control

The use case is aimed to utilize reactive power provision capabilities of RES and DER, as well as emerging technologies in the distribution grids to increase RES hosting capacity and to improve voltage profiles both at transmission and distribution levels. This will lead to maintaining the voltage quality, active power flow coordination at the TSO-DSO interface, effective participation mechanisms for voltage and reactive power control by RES and DG, and grid losses decrease.

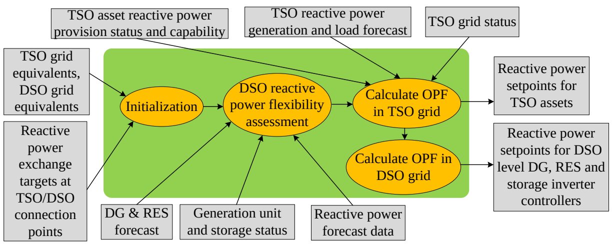

Figure 1. Context diagram of Use Case 1.

As shown in Figure 1, after gathering the necessary data, an optimal power flow (OPF) calculation is performed at DSO level to define the maximum and minimum available reactive power from the controllable sources. Then, the TSO uses the reactive power flexibility communicated for the whole grid group and the values declared for each connection point to run an OPF. The results will be set points for the TSO reactive power sources and TSO-DSO connection points. Finally, DSO computes the set points through its OPF tool by respecting set points given by TSO for its control area.

Use Case 2: Grid congestion management

The use case is aimed to mitigate/avoid grid congestion problems to improve system security and reliability. This will lead to maintaining grid balance, increase in availability of new active resources, increase in the network flexibility, and increase in TSO-DSO interaction.

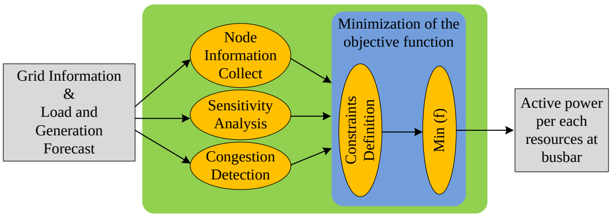

Figure 2. Context diagram of Use Case 2.

As shown in Figure 2, the grid data as well as the load and generation forecast data are first collected. Then, the data related to the connected resources (Pmin, Pmax, power reserves, etc.) are collected for each busbar. The load flow sensitivities is thus performed to calculate the sensitivities coefficients for each line. The congestion detection function allows evaluating possible congestions in the grid. If congestion is detected, the next step will be the definition of operation constraints for each line, which are formulated in order to avoid all possible grid violations in rescheduling of generation. Finally, based on these constraints, by minimizing the square of the rescheduling of generation, it will be possible to obtain the optimal active power value per each busbar (ΔP^+ and ΔP^-), and thus solve the congestion problem. The control logics described above can operate both at DSO level by operating on the available resources connected at distribution level, and at TSO level by operating on the available resources connected at both transmission and distribution levels.

Use Case 3: Frequency tertiary control based on optimal power flow calculations

The use case is aimed to improve frequency stability through provision of frequency tertiary control/reserve based on optimal power flow calculations and by involving as much as possible the flexible Renewable Energy Resources (RES) available at both transmission and distribution levels. This will lead to maintaining the grid balance and frequency stability, TSO-DSO active power flow coordination, maximising the RES and DG share in frequency control and balancing, and grid losses and generation costs decrease.

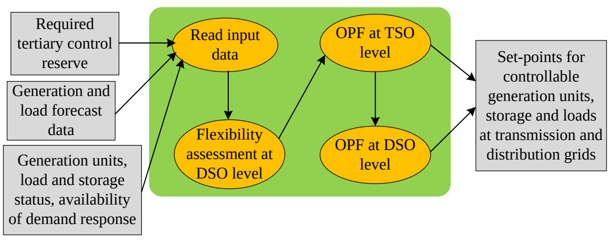

Figure 3. Context diagram of Use Case 3.

As shown in Figure 3, after gathering the necessary data, an OPF calculation is performed at DSO level to define the maximum and minimum available active power from the controllable sources. Then, the TSO uses the active power flexibility communicated for the whole grid group and the values declared for each connection point to run an OPF. The results will be set points for the TSO active power sources and TSO-DSO connection points. Finally, DSO computes the set points through its OPF tool by respecting set points given by TSO for its control area.

Use Case 4: Fast Frequency Restoration Control

The use case is aimed to fast frequency restoration in interconnected power systems based on a bottom-up approach through local measurements (tie-line power-flow deviations). In detail, this control logic allows achieving a frequency restoration process which is faster than that attained with the traditional controllers commonly used in power systems, through the use of local fast ramping resources (e.g., RES, storage and flexible loads), as well as enhanced TSO-DSO collaborative interaction. Beside to the reduction in the time needed to restore frequency, this control logic leads to maintaining the grid balance, improving the DER participation in providing ancillary services, and fostering TSO-DSO collaborative approach.

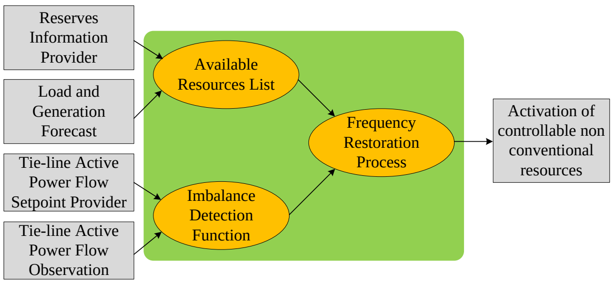

Figure 4. Context diagram of Use Case 4.

As shown in Figure 4, once the required information related to reserves, and load and generation forecast data is collected, the available resources in the grid (e.g., cost and available power) are listed according to predefined characteristics. The individual tie-lines active power flows schedules and measurements values of tie-lines power flows are used as input for the imbalance detection function, where the measured tie-lines active power flows are compared with the associated set points, to define a balance error signal to be sent to the frequency restoration process function. This latter, when an imbalance occurs (i.e., deviation from the setpoints), sends active power dispatch commands to controllable units for restoring the frequency, based on the information coming from the available resource list. This latter takes into account fast ramping resources connected at distribution level, therefore, the TSO, who is responsible for frequency restoration process in its control area, can benefit from the usage of fast resources connected at distribution level through a collaborative approach with DSOs.

Use Case 5: Power balancing at DSO level

The use case is aimed on minimisation of the energy flow between transmission and distribution networks by optimal power flow control at DSO level. This will lead to reduction of energy flow between transmission and distribution networks, optimal usage of flexible resources, and avoiding congestions and unnecessary grid losses.

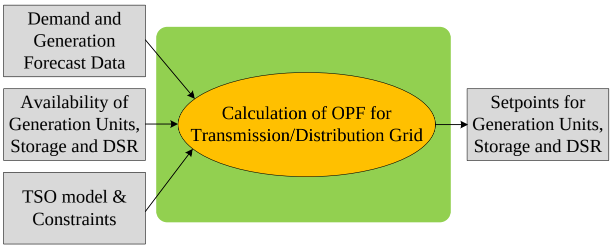

Figure 5. Context diagram of Use Case 5.

As shown in Figure 5, after gathering the necessary data, the OPF is performed for the transmission/distribution gird, where in this case 110 kV grid is considered to be meshed. As a result, the set-points for generating units, storage systems and demand side response (DSR) are obtained.

Use Case 6: Inertia management

The use case is aimed to develop an approach for inertia management in systems with significant RES penetration resulting in low system inertia. This will lead to limiting the rate of change of frequency (RoCoF) and frequency max/min deviations, maximising DG/RES contribution to ancillary services, and maintaining frequency stability in reduced inertia systems.

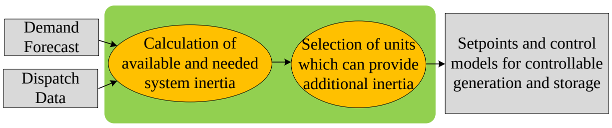

Figure 6. Context diagram of Use Case 6.

As shown in Figure 6, after gathering the necessary data, the available and minimum needed system inertia (based on maximum allowable RoCoF) are estimated. Then, in case of lacking inertia, the selection of units which can provide additional inertia is performed and validated through the dynamic simulation. As a result, the setpoints and control modes for controllable generation and storage systems are obtained.

Use Case 7: Optimal generation scheduling and sizing of DER for energy interruption management

The use case is aimed on securing the continuity of supply by minimising energy interruptions for a given set of contingencies while maximising the share of RES in the network. This will lead to minimising the energy interruption during a contingency event, minimising the energy losses in the network, increase in the network hosting capacity, and energy interruption scheduling to maximise the reliability of the network.

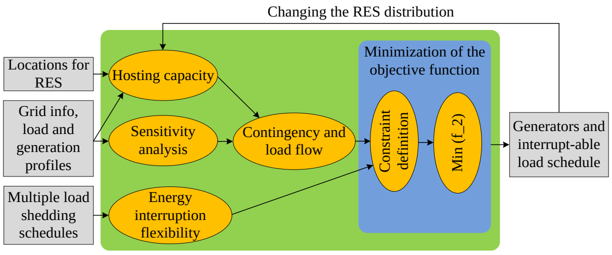

Figure 7. Context diagram of Use Case 7.

As shown in Figure 7 after gathering the necessary data, a load flow calculation is performed at TSO and DSO level to identify the critical nodes as candidates for credible contingencies. Concurrently, the hosting capacity is calculated to define the maximum level of RES that can be integrated at the given locations in the grid. Afterwards, a contingency is activated in the grid and load flow is performed. Based on the "contingency and load flow" and "energy interruption flexibility", it defines the constraints for the optimisation problem, which is energy interruption minimisation. The results for TSO/DSO to use is generators re-dispatch and interruptible loads schedule.

As for showcases, in INTERPLAN project, they are understood as "presentation of use case(s) in the frame of chosen scenario, simulation type, test model, time-series data and planning criteria". In total, five showcases were defined for the operation planning tool. Additionally, for each showcase a base showcase was created – which is a showcase "with no planning criteria and no controllers for emerging technologies" – in order "to analyse the operation challenges of the related use case(s) and improvements achieved through the application of planning criteria with related implementation of controllers in the associated showcase".

The planning criteria considered in the show cases are consisting of: assuring transient stability, assuring frequency stability, assuring voltage stability, maximizing DG/RES contribution to ancillary services, optimising TSO-DSO interaction, minimising energy interruptions, minimising generation and transmission costs, and minimising losses. The INTERPLAN showcases are presented below.

Showcase 1: Low inertia systems

This showcase combines inertia management (UC6) with fast frequency restoration control (UC4). Frequency stability of the first swing in the proposed solution is managed by estimating available and needed inertia for given system conditions, and followed by utilizing the needed inertia through synthetic inertia and fast frequency response controllers. For further reinforcements, OPF-based frequency restoration is added, which by using available energy sources brings the frequency to its nominal value.

Showcase 2: Effective DER operation planning through active and reactive power control

This showcase combines coordinated voltage/reactive power control (UC1) with grid congestion management

(UC2). The focus of this showcase is to present a control scheme to improve TSO-DSO coordination, both in managing the grid for voltage stability and solving the congestion issues occurring at all voltage levels. Applying a coordinated TSO-DSO optimisation methodology, this showcase aims to regulate active and reactive power flows by using TSO and DSO power assets, including utilisation of the DSO flexibilities to respect TSO optimization objectives and restore the grid in the presence of congestion events.

Showcase 3: TSO-DSO power flow optimization

This showcase combines frequency tertiary control based on optimal power flow calculations (UC3) with power balancing at DSO level (UC5). The main focus of this showcase is to present an optimization strategy for energy flow management between transmission and distribution grid, ensuring the balance within a distribution network on one hand and on the other hand for participation of non-synchronous energy resources in the tertiary reserve market and supporting the TSO in keeping the whole network stable.

Showcase 4: Active and reactive power flow optimisation at transmission and distribution networks

This showcase combines coordinated voltage/reactive power control (UC1) with frequency tertiary control based on optimal power flow calculations (UC3). Central concern of this showcase is to present an optimization strategy for parallel control of active and reactive power at transmission and distribution levels, for preserving the voltage quality at both network levels on one hand, and on the other hand for participation in the tertiary reserve market and supporting TSO in maintaining the complete network stable. The control strategy must ensure an optimisation of both active and reactive power of all available resources with no conflict in set points considering the constraints.

Showcase 5: Optimal energy interruption management

This showcase, which is based on use case 7 demonstrates a tool that performs optimal energy interruption scheduling and generator dispatch, while minimising the total energy interrupted in the network. Grid congestion resulting from a contingency is an important consideration. The critical lines and buses are identified, and the sensitivity analysis is performed to prioritize resources that reduce the likelihood of grid congestion and voltage constraint violation.

SUMMARY AND OUTLOOK

In this paper, an overview of the main intermediate results achieved in INTERPLAN H2020 project are presented and discussed. The project aims to develop an integrated operation planning tool towards the pan-European electricity network, by considering all network levels with a key focus on TSO-DSO interactions. The main findings of the analysis on existing grid codes and regulations at European and National levels are discussed, and the INTERPLAN scenarios are presented. INTERPLAN use cases, which are strongly driven by the presented scenarios, look beyond the current regulations and grid codes, and propose solutions to face the challenges that high shares of technologies, like RES, storage and DR will implicate for operation planning of the grid. Besides, a set of showcases for the operation planning tool with goals such as minimising losses, minimising costs, optimising TSO-DSO interactions, maximising DG/RES contribution to ancillary services, are presented.

As a key component for this integrated tool, it is necessary to develop grid equivalents that enable this joint analysis, considering all relevant voltage levels. A generic methodology for grid clustering, that is applicable to all use cases in INTERPLAN, is being developed. This framework initially identifies the relevant regressors (i.e., grid parameters or linear/nonlinear combinations) for each use case, and following this selects an appropriate machine learning algorithm that determines the optimal number of clusters, and finally, selects a set of representative networks. In the further stages of the project, performing dynamic and semi-dynamic simulations of grid equivalents for the established base showcases, will allow analysing the operation challenges identified in the use case(s), and investigate the possible intervention measures. Then, the application of planning criteria with related implementation of controllers in the showcases, will allow applying these intervention measures through cluster and interface controllers. These latter combined with the grid equivalents library represent the tool set of the INTERPLAN tool, which will allow grid operators to solve a significant number of operation challenges of the current and the future 2030+ EU power grid within the chain transmission-distribution and with a key focus on TSO-DSO interface.

ACKNOWLEDGMENTS

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