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Grid simulations and simulation tools. Preliminary results

D6.3

EU-SysFlex

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ABBREVIATIONS AND ACRONYMS

AB	Advisory Board
AMR	Automatic Meter Reading
beeDIP	System platform for data integration and pilot systems in network operations management
BESS	Battery energy storage system
CA	Consortium Agreement
CGMES	Common Grid Model Exchange Standard
CIM	Common Information Model
DB	Demonstration Board
DER	Distributed Energy Resource
DoA	Description of Action
DSO	Distributed System Operator
EC	European Commission
EC-GA	European Commission -Grant Agreement
EHV	Extra High Voltage
EU-SYSFLEX	Pan-European System with an efficient coordinated use of flexibilities for the integration of a large share of Renewable Energy Sources (RES)
EV	Electric Vehicle
FCR-D	Frequency Containment Reserve for Disturbances
FCR-N	Frequency Containment Reserve for Normal Operation
FFR	Fast Frequency Reserve
GA	General Assembly
GCP	Grid Connection Point
HV	High Voltage
IEE	Fraunhofer Institute for Energy Economics and Energy System Technology
LV	Low Voltage
mFRR	Manual Frequency Restoration Reserve
MO	Management Office
MV	Medium Voltage
NCM	Network Congestion Management
OFRS	Offline real-time simulation
OFSS	Offline static simulation
OLTC	On-Load Tap Changer
ONRS	Online real-time simulation
P	Active Power
PC	Project Coordinator
PF	Power Factor
PMB	Project Management Board
PS	Primary Substation
PV	Photo-Voltaic
Q	Reactive Power
TM	Technical Manager
TSO	Transmission System Operator
WLS	Weight Least-Square
WP	Work Package

EXECUTIVE SUMMARY

The EU-SysFlex H2020 project aims at a large-scale deployment of solutions, including technical options, system control and novel market designs to integrate a large share of renewable electricity, increasingly variable, maintaining the security and reliability of the European power system. The project results will contribute to enhance system flexibility, resorting to both existing assets and new technologies in an integrated manner, based on seven European large scale demonstrators (WP 6, 7, 8 and 9). The overall objective of WP6 is the analysis and demonstration of the exploitation of decentralized flexibility resources connected to the distribution grid for system services provision to the TSOs; this objective is pursued by the means of three physical demonstrators located in Germany, Italy and Finland, using different assets located at complementary voltage levels (high, medium and low voltage) of the distribution grid. These demonstrations showcase innovative approaches in flexibility management targeted to support transmission system operators' (TSO) and distribution system operators' (DSO) needs and their related services, identified within the EU-SysFlex H2020 funded project. These approaches are followed by the means of suitable system processes which have been described in terms of System Use Cases (SUC) and presented in deliverable D6.1. The functionalities identified within the SUC modelling have been mapped into four main software tools groups, namely communication tools (D6.4), forecast tools (D6.2), simulation tools (D6.3) and optimisation tools (D6.5), the development of which is the main goal of Task 6.3. These tools are described in four corresponding deliverables: this deliverable, D6.3, is part of this set and addresses the simulation tools and preliminary tests of demonstrator's set-ups carried out with these tools.

Simulations take on a great importance in the investigation of demonstrator networks' handling and operations in scenarios which differ from the Business-as-Usual, like those envisioned in the EU-SysFlex project. Furthermore, simulations serve as a testing, de-risking and validation environment for the other tools, in preparation of their deployment in the physical demonstrations set-ups. Therefore, within the Work Package 6 activities, the simulations take on two main purposes: investigating specific operating conditions, in line with the project assumptions and scopes, which cannot be replicated and tested in the physical set-ups of the demonstrators, and testing the operations and the reliability of the software parts (tools and systems) of the demonstrator set-ups.

Suitable scenarios, which model novel flexibility management within the actual demonstrator networks, are simulated for different objectives: assessing the flexibility potential of these networks, its impact on the distribution network constraints and, in general, the performances of the demonstrations set-ups in presence of the specific operating conditions, which may arise from the exploitation of the decentralised resources for flexibility provision to the TSO. Such scenarios may be beyond the technical capability of the networks and systems and also beyond the regulations presently in effect: simulations show possible ways to deal with these scenarios and so, in addition to their contribution to the demonstrators' activities, the achieved results support further analysis on the evolution of the electric power networks.

The selected scenarios are strongly influenced by the different features and background of each demonstrator and so, the adopted simulation approaches reflect such differences. Therefore, the scopes and goals of simulations in the context of each demonstrator are analysed and described, highlighting the relevant differences between the adopted approaches. The envisioned goals are put in relation with the overall objectives of WP6,

showing how and to what extent simulation activities contribute to them. Simulations represent a part of the whole demonstrators' activities, and they are also a part of a larger set of tools under Task 6.3 so they are not intended to fulfil the WP6 objectives stand alone. However, the simulation tests presented in this deliverable fully contribute to the achievement of WP6 objectives, since they support the pursuing of an optimal state for the distribution network and also, indirectly, the fulfilment of specific requests from TSOs, which are two key goals in the WP6 activities.

Simulation tests carried out for German demonstrator are aimed at analysing the impact of different reactive power control modes and asset behaviours in HV distribution network on the status of EHV transmission network; in parallel, the simulation environment was exploited to evaluate preliminary optimisation results. These activities were carried out both with simulated data and with historical data coming from a real voltage collapse event. Simulation tests results demonstrate that the reactive power flexibility optimization from the DSO offers the best results in achieving a more effective local and global voltage stabilisation. The system and methods developed within the German demonstration show promising application in exploiting local reactive power flexibility as a systematic way to sustain the local voltage stability; the inclusion of DERs from the MV distribution network can further support this concept, increasing the available flexibility.

Simulation tests carried out for Italian demonstrator are aimed at determining the actual range of total active and reactive power capability of the demonstrator network (MV radial distribution network), as well as to investigate the scalability of flexibility potential for different network scenarios and different types of resources and the corresponding impact on network constraints. Test results show that the resulting capabilities for different resources set-ups (case scenarios) can virtually allow very high degrees of freedom for power exchange at primary substation. From case scenarios analysis it can be observed that the predominance of PV plants results in wide capability areas but their full exploitation in the hot season can cause voltage violations; on the other side, the exploitation of dedicated assets (i.e. STATCOMs in this case) can extend the power modulation in other time periods and can potentially overcome the issues related to local voltage violations.

Even if simulation tests and the corresponding results presented in this deliverable reflect the specific characteristics of the demonstrator set-ups to which they are applied, the developed simulation tools are designed to model potentially every network scenario, in order to perform a broader range of analysis. Furthermore, from the holistic point of view pictured by the single theoretical grid infrastructure presented in D6.6, the developed simulation tools can potentially be exploited jointly, enlarging the boundary of the analysis and allowing to study more complex scenarios. This versatility enhances scalability and replicability of simulation tests.

1. INTRODUCTION

The EU-SysFlex project seeks to enable the European power system to use efficient, coordinated flexibilities in order to integrate high share of Renewable Energy Sources (RES). One of the primary goals of the project is to study the European power system with at least 50% of electricity coming from RES, an increasing part of which is made up of variable, distributed and Power Electronic Interfaced sources (i.e. wind and solar). Therefore, the EU-SysFlex project aims at a large-scale deployment of solutions, including technical options, system control and a novel market design to integrate a large share of renewable electricity, maintaining the security and reliability of the European power system.

In order to achieve the project objectives, the EU-SysFlex approach pursues the identification of technical shortfalls requiring innovative solutions, the development of a novel market design to provide incentives for these solutions, and the demonstration of a range of innovative solutions responding to the shortfalls. Other activities such as data management analysis, innovative tool development and integration and testing of new system services in TSOs control centres are also included in the project approach. The project results will contribute to enhance system flexibility, resorting both to existing assets and new technologies in an integrated manner, based on seven European large scale demonstrators in Germany, Italy, Finland, Portugal (2), France, and the Baltic states (Work Package (WP) 6, 7, 8 and 9).

It is the project's goal to increase the flexibility of the future European system by developing the capability to provide not only the energy, but also the reliability and stability, through system services, required to integrate high RES. Therefore, **Work Package (WP) 6 *"Demonstration of flexibility services from resources connected to the distribution network"*** analyses the opportunities arising from decentralised flexibility resources connected to the distribution grid to serve the needs of the overall power system, enhancing the coordination between DSOs and TSOs, by means of three demonstrators located in Germany, Italy and Finland.

1.1 WP 6 OBJECTIVES AND RELATIONSHIPS BETWEEN TASKS

As stated above, the primary objective of the WP6 is to analyse and test the exploitation of decentralised flexibility resources focusing on ancillary service provision from resources connected to the distribution grid according to the needs of DSOs and TSOs. This process is highly challenging for both, since it is based on the integration, and exploitation, of large amount of RES in the grid structure (in line with the current policies for the decarbonisation of the energy systems) guaranteeing, at the same time, the security and resilience of their networks. Anyway, DSOs and TSOs can take advantage of the increasing share of flexible resources and specifically DSOs can actively support TSOs making available distributed flexibilities to the transmission networks by the means of improved network management systems and enhanced cooperation processes. In detail, three sub-objectives can be identified:

- Improve TSO-DSO coordination;
- Provide ancillary services to TSOs from distributed system flexibilities;
- Investigate how these flexibilities could meet the needs of both TSOs and DSOs.

WP 6 addresses these objectives through five interlinked tasks. Task 6.1 is related to needed Work Package coordination. Task 6.2 focuses on the definition of System Use Cases (SUC) based on the Business Use Cases (BUC) coming from WP3. Within Task 6.3, systems and tools are being developed in order to set up the SUC. In Task 6.4, field tests will be carried out in the three demonstrators. Furthermore, the results of these field tests will be analysed and common conclusions will be drawn in Task 6.5. A schematic overview of all the relationships described above is presented in Figure 1.1 (derived from a similar figure presented in D6.1 *"Demonstrators Use Cases description"* [1]) :

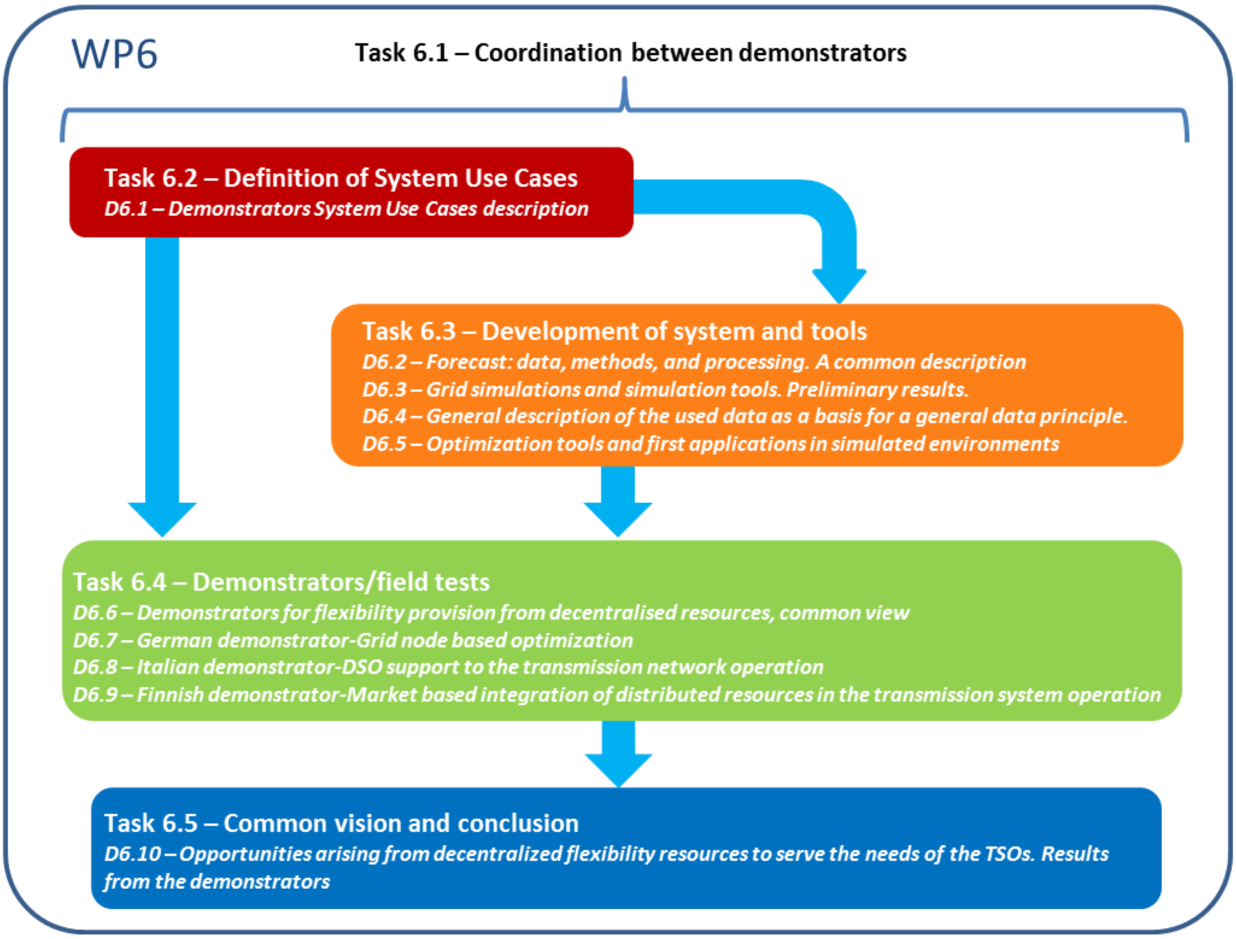


FIGURE 1.1 – WP6 OVERVIEW AND RELATIONSHIPS WITHIN TASKS

The activities and achievements of each Task, and of the whole Work Package itself, will be presented through a comprehensive set of deliverables. In the following, they are shortly described, divided by Task:

- Task 6.2 *"Definition of System Use Cases"*:
  - Deliverable 6.1 *"Demonstrators Use Cases description"* presents the "translation" of Business Use Cases from WP3 into System Use Cases

- Task 6.3 *"Development of systems and tools"*:
  - Deliverable 6.2 *"Forecast: Data, Methods and Processing. A common description"* presents the description of requirements of the DSO/TSO interface, in order to harmonise the data formats and models for all the trials;
  - Deliverable 6.3 *"Grid simulations and simulation tools"* presents the first results about network models and simulations from the demonstrators;
  - Deliverable 6.4 *"General description of the used data as a basis for a general data principle"* presents the description of communication interfaces between the actors involved in the demonstrators;
  - Deliverable 6.5 *"Optimization tools and first applications in simulated environments"* presents the description of the optimisation tools and the range of flexibilities used in the demonstrators;

- Task 6.4 *"Demonstrators/field tests"*:
  - Deliverable 6.6 *"Demonstrators for flexibility provision from decentralized resources, common view"* presents the deployment plan, including technical specifications, procurement procedures for technical equipment, timeline for installations, and monitoring procedures;
  - Deliverable 6.7 *"German demonstrator - Grid node based optimization"* presents the information about the German demonstrator results, including the description of the working framework;
  - Deliverable 6.8 *"Italian demonstrator - DSO support to the transmission network operations"* presents the information about the Italian demonstrator results, including the description of the working framework;
  - Deliverable 6.9 *"Finnish demonstrator – Market based integration of distributed resources in the transmission system operations"* presents the information about the Finnish demonstrator results, including the description of the working framework;

- Task 6.5 *"Common vision and conclusion"*:
  - Deliverable 6.10 *"Opportunities arising from the decentralized flexibility resources to serve the needs of the TSOs. Results from the demonstrators"* presents common conclusions and recommendations from the demonstrators' activities, in order to contribute to the WP objectives and overall Project results.

The current deliverable, D6.3 "Grid simulations and simulation tools. Preliminary results." is part of T6.3 "Development of systems and tools". The scope of Task 6.3 is to develop the algorithms and the software tools, which embed the innovative functionalities and the corresponding requirements defined in the System Use Cases, presented in D6.1 [1]. Task 6.3 deals with four groups of tools, divided by the type of application (forecast, simulation, communication and optimisation), which are presented and described in four corresponding deliverables (from D6.2 to D6.5, [1]). These groups of tools will be integrated in the demonstrator set-ups in order to carry out the field tests which are the scope of Task 6.4 and will be described in a dedicated set of deliverables (D6.7, D6.8 and D6.9 respectively). This deliverable (D6.3) deals with the description of simulation tools and their application into new scenarios (derived from the Use Cases described in deliverables D3.3 [1]) modelled onto the demonstrator set-ups.

1.2 SCOPE AND OBJECTIVE OF THIS DELIVERABLE

As shortly explained in the previous section, this deliverable is part of a set of four deliverables, the goal of which is to present and describe the activities of Task 6.3 and the corresponding software tools and algorithms to be exploited within the WP6.

Each deliverable deals with a specific type of tools and algorithms, which are shortly described in the following:

- Observability and forecasting tools: these tools are aimed to improve forecasts of variable resources generation and availability for additional services, of the market, of the network needs and of how the distributed resources would behave in presence of price and control signals. They are developed within the context to meet specific characteristics of the different demonstrators. Nevertheless, the overall requirement is to achieve a higher observability of the system and hence more accurate network states and market scenarios. These tools are presented and described in deliverable D6.2 *"Forecast: Data, Methods and Processing. A common description"* [1].
- Grid simulation tools: these tools, and the simulation tests carried out through their exploitation, are aimed to investigate different handling and operations of the demonstrator networks. Suitable scenarios, which model novel flexibility management within the actual demonstrator networks, are simulated in order to assess different objectives. The flexibility potential of these networks, its impact on the distribution network constraints and, in general, the performances of the demonstrations set-ups in presence of the specific operating conditions, which may arise from the exploitation of the decentralised resources for flexibility provision to the TSO. In addition, simulations serve as a testing and validation environment for the other tools, in preparation of their deployment in the physical demonstrations set-ups. Simulation tools and simulation tests results are presented and described in this deliverable D6.3 *"Grid Simulations and simulations tools. Preliminary results"* [1].
- Communication tools: these tools are aimed to support the communication interfaces between the actors and systems involved in the demonstrators. The existing communication platforms are improved, and new interfaces are defined, in order to allow interactions between the involved actors, based on processes described in the Use Cases. These tools are presented and described in deliverable D6.4 *"General description of the used data as a basis for a general data principle"* [1].
- Optimisation tools: these tools are aimed to determine and use the range of flexibilities, which are provided by distributed resources and needed for better coordination and integration, providing the different services and products which are required by the TSO. These tools enhance the existing demonstrator infrastructures and systems, enabling the optimal use of the tested controllable assets (i.e. RES, battery energy storage system (BESS), Static Synchronous Compensators (STATCOM), electric vehicles (EV), heat storages). These tools are described in deliverable D6.5 *"Optimization tools and first applications in simulated environments"* [1].

The global scope of this deliverable is to describe the simulation approaches adopted within WP6 and to explore the new operating conditions the demonstrator networks have to face, in presence of distributed assets flexibility exploitation aimed at proving ancillary services to the TSO. Despite the common goal to provide flexibilities and more information to the TSO, the outcomes of the simulation tests and the simulation approaches themselves reflect the different features and background of each demonstrator.

Figure 1.2 depicts the relationships between the four subjects of Task 6.3 and demonstration activity of Task 6.4, showing the different simulation philosophies adopted for demonstrators. The tools developed and enabled within these four deliverables are the core properties of each demonstrator developed in WP6.

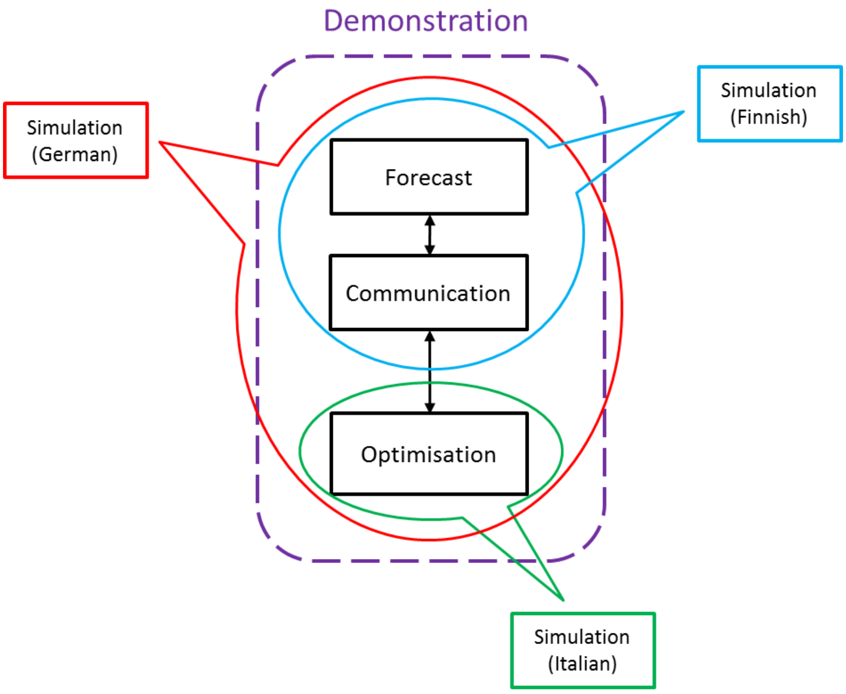


FIGURE 1.2 – RELATIONS AND DEPENDENCIES BETWEEN THE FOUR SUBJECTS AND TOOLS WHICH ARE TREATED WITHIN TASK 6.3.

As seen in the Figure above, three groups of tools (i.e. *Forecast*, *Communication* and *Optimisation*) will be applied to the physical demonstration field tests: each demonstrator (German, Italian and Finnish) will exploit its own forecast, communication and optimisation functionalities. Anyway, even if all demonstrators share a common philosophy in this sense, they have different simulation needs, based on the features and background of each demonstrator set-up: the specific scope and goals of the simulation tests are briefly presented in the following and they will be analysed more in detail in Chapter 2.

GERMAN DEMONSTRATOR

This demonstrator set-up is applied in a part of the German high-voltage distribution network; its main scope is to plan and coordinate distributed energy resources (DER) connected to high-voltage grids in order to enable the provision of suitable active and reactive power (P-Q) flexibility to the DSO high-voltage (HV) distribution grid and to the TSO extra-high-voltage (EHV) transmission grid in order to handle possible foreseen congestions and control voltage profiles of the grid. Its goal is to demonstrate that the coordination with DSO for flexibility exploitation may be more reliable and efficient in respect to the actual approach, i.e. the TSO solve network issues on its own, superimposing potentially violations to the distribution network operations. This goal is pursued through the generation of suitable, congestion free P-Q maps and P and Q flexibility ranges that can be accessed by the TSO, and improving the communication between DSO and TSO. Since the German demonstration proposes a completely new operating approach and a new integrated physical set-up, the simulations are needed for two reasons: assessing the proper functioning of the developed algorithms in the whole system in preparation for the field tests and investigating how the demonstrator set-up performs when applied to some real cases.

ITALIAN DEMONSTRATOR

This demonstrator set-up is applied in a part of the Italian medium voltage distribution network; its main scope is to exploit the controllable assets connected to distribution network for supporting ancillary service provision to high voltage transmission network. Its goal is to demonstrate that the already connected DERs plus some dedicated assets (BESS, STATCOM) may be managed and optimised locally by the DSO in order to provide suitable and congestion free P-Q flexibility range for TSO at primary substation. This goal is pursued through the provision of aggregated reactive power capability and a cumulative parametric curve (energy/cost) for active power. The concept of the aggregation of flexible resources at distribution level is a substantial innovation for the Italian national scenario. The aim of simulations is to estimate how much flexibility could be achieved for different scenarios and to assess, which range of flexibility could be actually exploited without violating the distribution network constraints, i.e. guaranteeing safe and efficient operations of the distribution network.

FINNISH DEMONSTRATOR

This demonstrator set-up deals with aggregator activities related to flexible resources in low and medium voltage grids. These flexible resources can be e.g. customer-owned batteries, public EV charging stations or large-scale batteries. Its main scope is to manage the low and medium voltage flexible resources, in order to allow active power to be exploited in the TSO ancillary service market and for reactive power services to the DSO. Its goal is to increase the revenues achievable from the operations of flexible assets and it is pursued through innovative aggregation approaches and a novel reactive power market concept. The investigation of different operating conditions in presence of flexibilities exploitation, which is the main objective of the simulation tests, for the Finnish case falls, respectively, in market optimisation for the active power services and in PQ window forecast for the reactive power services. Both these tasks do not require any network simulation and therefore the relevant simulations (market simulations) for the Finnish demonstrator are not in the focus of this deliverable: they will be presented in other documents. i.e. deliverables D6.2 and D6.5 [1].

The scopes and goals described above, even if specifically focused on the needs of each demonstrator, are aligned with the overall objective of the WP6, i.e. “analyse the opportunities arising from decentralised flexibility resources connected to the distribution grid to serve the needs of the overall power system”.

Simulation tools and approaches described so far represent a part of the whole demonstrators’ set-ups, so they may not completely fulfil the WP6 objectives on their own, since the demonstrators activities in their entirety are meant to do that. Besides this, it is clear from the above descriptions that simulation tests support, even if in a different way and extent, the Work Package objectives described in section 1.1, here reported again for clarity:

- Improvement of TSO-DSO coordination

- Provision of ancillary services to TSOs from flexibilities in the distribution system.
- Demonstrating how flexibilities in the distribution grid can be used to meet the requirements of both DSO and TSO.

A final assessment of the contribution of simulation tools and approaches to the Work Package objectives is presented in Chapter 5.

The simulation tests carried out within Task 6.3, inevitably, envisioned scenarios which may be beyond the technical capability of the networks and systems and also beyond the regulations presently in effect; moreover they show possible ways to deal with these scenarios and so, in addition to their contribution to the demonstrators activities, the simulation results could be relevant for TSOs, DSOs, National Regulatory Boards, Research Associations and all the other entities and stakeholders, directly or indirectly, involved in the evolution of the electric power networks.

In the following chapters, the simulation activities are analysed in detail for each demonstrator, taking into account their impact on other demonstrations activities, assessing their contribution to the overall objectives, as well as how they complement and support each other, leading to a holistic approach suitable for future challenges. Furthermore, the results achieved from simulation tests are presented and discussed. These results are to be considered preliminary, since they aim at verifying the operations and the reliability of the tools and systems and investigating specific operating conditions in preparation for field tests: they will be complemented by the results from the field tests which will be presented and reviewed in deliverables D6.7, D6.8 and D6.9.

1.3 STRUCTURE OF THIS DELIVERABLE

This deliverable is meant to be comprehensible and self-contained in content but, since it is part of the set of deliverables in Task 6.3, it must be always considered as one part of a larger series, as explained in chapter 1.1.

The document structure is as follows:

- Chapter 2 describes the **general objectives of each simulation** within their specific environments, highlight differences and communalities between the approaches followed, and also point out the innovations which come along with these new approaches;
- Chapter 3 and Chapter 4 present the simulation approach and first results on **simulated scenarios for the German and Italian demonstrator** respectively;
- Chapter 5 describes how the simulation approaches could be used in a **combined application, in an holistic view**;
- Chapter 6, as a conclusive chapter, provide a **summary and an outlook** with ongoing research and open questions.

2. OVERVIEW OF SIMULATION APPROACHES WITHIN WP6

Within the Work Package 6 activities, the simulations take on two main purposes: testing the operations and the reliability of the software parts (tools and systems) of the demonstrator set-ups and investigating specific operating conditions, in line with the project assumptions and scopes, which cannot be replicated and tested in the physical set-ups of the demonstrators. Both these tasks need to take place in between the development of algorithms and software tools and the field test activities (Figure 2.1). In the development track, simulations serve as a check for the development work, for assessing the reliability and correctness of the software coding as well as for gaining valuable feedbacks for further improvements. In addition, they serve as a preparation for the testing activities to be carried out within the physical set-ups, returning a preliminary analysis, which is helpful for setting the suitable operating conditions for field tests.

FIGURE 2.1 – DEVELOPMENT TRACK IN WP6

As briefly described in section 1.2, despite sharing the global scope and objectives, simulations approaches are combined differently between the demonstrators, because of features, constraints and specific needs of each demonstrator set-up. How these approaches will look like and how they compare to each other and what questions and challenges can be solved by them, will be shown in the following sections.

2.1 OBJECTIVES OF SIMULATION WITHIN WP6 DEMONSTRATORS

In this section, the specific characteristics of the simulation approaches adopted for each demonstrator are analysed in detail, giving a complete view of the objectives pursued through simulation tests. In addition, the reasons why network simulations are not necessary for the Finnish demonstrator are explained in detail. In the next chapters of this document the simulation activities of German and Italian demonstrators will be presented.

GERMAN DEMONSTRATOR

The German demonstration is based on a part of high voltage distribution grid in the east of Germany, connected via 16 HV/EHV primary substations to the EHV transmission network and characterized by high installation of distributed energy resources (DERs) and relatively low load. While the population and industrial centre in Germany is mainly located in south and west, this imbalanced distribution of the energy generation and energy demand causes currently often congestions on the transmission grid. With increasing generation connected at distribution level (DER), the exploitation of flexibility of distribution grid to solve transmission congestion (EHV) is a priority. The main question that needs to be answered is how to utilise the flexibility under the prerequisite of local grid safety. The local limitation will be considered in the optimisation tool and further introduced in detail in deliverable 6.5 [1].

Within the German demonstration DER flexibilities are aggregated at the grid connection points (GCPs) by the DSO Mitnetz supporting the TSO's (in the German case 50Hertz) congestion management and voltage control. It is expected that this aggregation and use of flexibilities give both technical and economic advantages. The current German Energy Act allows already the utilisation of ancillary service from connected DERs and will be even more liberal and transparent in the future. According to the latest law change, an effective and economical use of the flexibility in solving grid congestion is requested. The scope and goals of the German demonstration of project EU-SysFlex matches exactly this request. The demonstrator to be implemented for the DSO Mitnetz would be a key point in fulfilling the request. To implement such a complex system at the grid control centre, it is essential to test, de-risk and verify the demonstrator before applying to the physical assets. The grid simulation with real-time capability is in this case the suitable method.

In the German demonstration, the grid simulator and grid optimisation are built as two independent parts; the co-simulation is realised through unified data interface and co-simulation tool. The real-time grid simulator is able to represent the grid status with enough accuracy and contains properly modelled assets. With the grid simulator, the optimisation tool of the German demonstration can be evaluated and further innovative research on the asset's local behaviour and its impact on the grid can be carried out.

As short conclusion, the simulation is required in the German Demonstration for the following reasons:

- Verification of grid topology and assets modelling,
- Analysis of impact of different assets' behaviours on the grid status,
- Evaluation of the preliminary optimisation results in the simulation environment.

The innovation brought by the grid simulation lies in its functionality and co-simulation capability with a remote demonstrator, and in the potential of application for further gird operational research purposes. In the real operation phase, a laboratory demonstration will be synchronised with the grid control centre as a so-called "digital twin" which will be set up in a later phase in parallel to the field test. A more detailed description will then be given in the deliverable 6.7. This concept describes a future scenario, in which a second system shares exactly the data interface and functionality of the original system as a backup and black box. For the German demonstration, a second system (the laboratory demonstrator as digital twin) can receive the same data as the DSO demonstrator. The grid simulator will be used for the verification of optimisation in the laboratory environment to serve as extra verification tool and analyse the potential risk under special cases.

The preliminary simulation results in this deliverable give a full functionality verification of the tool itself. Furthermore, the case study gives a deeper understanding of the grid impact of different assets' behaviours and the performance of the optimisation tool, which collects also valuable information for the field tests.

ITALIAN DEMONSTRATION

The Italian demonstration is based on a part of the Italian medium voltage distribution grid, connected via a HV/MV primary substation to the high voltage transmission network and characterised by a high penetration of DERs (mainly PV plants) and relatively low load (being in a mostly rural area). This network was formerly chosen as suitable test network for smart grid solutions, specifically network management systems and flexible assets, focused on improving the voltage control, reducing back-feeding, avoiding curtailment and increasing hosting capacity. For these purposes, an innovative software module was installed within the network SCADA system: the NCAS (Network Calculation Algorithm System) integrates the necessary algorithms for network optimisation in presence of flexible assets and it is able to cope with different types of constraints, including multi-temporal constraints. A detailed explanation of the optimisation functionalities included in the NCAS module is presented in deliverable D6.5 [1]. The NCAS module was not designed to perform off-line simulations, since it can be operated only within the SCADA system.

The provision of ancillary services from the distributed resources to the transmission network envisioned by the EU-SysFlex project, if applied to current Italian electricity system, would require a challenging change of perspective; indeed, the exploitation of power flexibilities from distributed resources in Italy, currently is not operational and the debate on this topic is ongoing, within the Regulation Authority. By present regulations, DSOs are neither allowed to aggregate nor to provide flexibilities to the TSO. In such conditions, the innovation extent endorsed by the EU-SysFlex Project translates into a completely new way to consider and perform network operations in the distribution networks. Hence, it is essential not only to improve the network management systems accordingly, but also to assess the actual potential of DERs, which can be aggregated at primary substation level. This task inevitably requires evolving from the actual physical arrangement of the demonstration network, modelling new network arrangements that allow DER flexibility exploitation.

For the reasons outlined above, a suitable simulation approach is identified: the NCAS algorithms are modified and installed in a dedicated simulation environment, in order to exploit the functionalities of the NCAS module in off-line operations and apply them to different operating scenarios, focused on the assessment of the flexibility potential of the demonstration network.

Specifically for the Italian demonstration, the objectives of the off-line simulations can be summarised as:

- Analysis of the actual range of total active and reactive power capability of the demonstrator network, within the primary substation boundary;
- Evaluation of different network scenarios, in order to investigate the scalability of flexibility potential for increasing numbers of flexible resources;
- Evaluation of the impact of flexibilities exploitation, in different operating conditions, on network constraints;
- Assessment of the relevance of exploiting different types of flexibility resources, including network assets (such as STATCOMs and BESS) and dispatchable energy sources.

The innovation brought by the simulation tests carried out for Italian demonstrator consists in the opportunity to extract a portrayal of network operations in presence of high levels of flexible RES, close to the operating conditions envisioned in the project assumptions. This type of analysis cannot be taken on relying upon the

physical demonstrator only. The corresponding results are very valuable for supporting the vision of distributed flexibilities exploitation for network purposes, both in Italian electricity system and in the pan-European context. Additionally, the simulation tests results can be used as a reference for preparing field tests and indicating, which resources cannot be exploited fully due to constraints violations, on which time the flexibility range is maximum or minimum and how many tap shifting at the MV/HV transformer are necessary to support flexibility exploitation while keeping voltage within the limits. Furthermore, results like where and when feeder congestions may arise as well as several more results will be useful. All this information can be used for defining coherent and sound test cases and to identify the suitable settings of the network assets to be applied in the field tests.
Concluding, the preliminary investigation performed through the simulation tests return a deeper knowledge of the network behaviour in specific operating conditions, facilitating the subsequent field tests and returning valuable information for the potential future evolution of distribution networks and corresponding regulations.

FINNISH DEMONSTRATOR

As briefly explained in Chapter 1, network simulations are not relevant for the activities related to Finnish demonstrator and hence they are not described in this document. However, the background of the Finnish demonstrator, its specific scope and objectives are reviewed and the reasons behind the choice to carry out market simulations instead of network simulations are explained in detail.

The Finnish demonstrator uses the flexibility of various assets connected to the medium and low voltage networks in order to provide frequency control services to the TSO and reactive power compensation services to the DSO. The purpose of the Finnish demonstrator is to look at the issues from the aggregator’s point of view and bring the market-driven aspect to WP6. The core of the Finnish demonstrator is not only to look at the demonstration from the technical characteristics, but also to determine the economic and market aspects of the solutions.

Regarding the active power services to the TSO, the small size and number of resources and the dimensioning of the distribution network in the demonstration area are such that using the assets’ flexibilities cannot cause congestion or voltage problems in the network. The distribution network in Helsinki city urban area is strong and robust and does not have issues with congestion. Furthermore, the Finnish demonstration will set-up the demonstration according to the existing TSO ancillary market rules, which do not involve local DSO. The operation in the TSO ancillary markets considered in the demonstration is between the TSO, the aggregator and the assets. Since the DSO does not take part in this TSO ancillary markets operation nor know which assets connected to the distribution network are participating in the markets, no network simulations of the distribution grid are performed nor needed for the frequency regulation provision to the TSO in the scope of the Finnish demonstration.

Regarding the reactive power services to the DSO, there is a need for the DSO to evaluate its needs in advance. The objective is to minimise the times and volumes by which the exchanges between the TSO and DSO wander out of the allowed PQ-window. The PQ-window refers to the TSO/DSO connection points and is set by the TSO. If the limits are exceeded, the DSO must pay penalty payments to the TSO. Based on experiences, it is estimated that a forecasting method based on past active and reactive power exchanges and on temperature forecasts, will give good results. Thus, a detailed network simulation is not envisioned in this case either. Therefore, the PQ-window estimation is a forecasting problem, which will be reported in *D6.2 Forecast: Data, Methods and Processing. A common description* [1].

In the Finnish demonstration, the objective is to increase the revenues obtained from the operation of the available, so far untapped, flexible assets. These assets are targeted to provide frequency services to the TSO through the existing frequency markets (such as the Frequency Containment Reserves for Normal operation (FCR-N) or in case of large Disturbances (FCR-D)). The balancing of the aggregator is also taken into account and future possible markets will be considered in simulations (such as a market similar to Ireland's Fast Frequency Reserves (FFR) market).

The purpose of the market simulation is to analyse the economic and market potential of aggregating small flexible assets connected to the distribution network to bigger entities eligible to the TSO ancillary markets. On the other hand, the Finnish demonstration will test a DSO reactive power market as a proof of concept. The demonstration will be a technical test with two assets, a large-scale battery and a PV plant. However, a vital aspect of the reactive power market demonstration will also be to evaluate whether the approach would be economically sustainable for the DSOs, aggregators and asset owners in the future.

Since market simulations differ highly from the purpose of this deliverable concentrating on the network simulation, the results of the market simulations performed by the Finnish demonstration are not included. The market simulations include the economic aspects for the aggregator and the asset owners. In the simulations, future potential of flexibility resources connected to the distribution network is evaluated. Since the DSO does not participate at all in these market operations nor know which assets are activated in the TSO's ancillary markets, no grid simulations are performed nor applied. The results of the market simulations will be reported in *D6.9 Finnish - Market based integration of distributed resources in the transmission system operation*.

2.2 COMMUNALITIES AND DIFFERENCES BETWEEN THE APPROACHES

In this section the two different network simulation approaches adopted for German demonstrator and Italian demonstrator are briefly compared, in order to highlight their main differences and communalities.

First of all, it must be noted that these two approaches must be necessarily different since they deal with different network topologies, different types of network management processes and different types of assets: as a results, the corresponding network simulations differ. Apart from the intrinsic differences related to the distinct demonstrator backgrounds, a significant difference between the approaches is how the algorithms, exploited for simulations, are arranged and built-up: in the German case a dedicated standalone modular software tool is developed, while in the Italian case the SCADA calculation algorithms are implanted in a custom one-off simulation environment. This aspect is influenced by another difference between the two approaches, i.e. the way they are intended to be applied within their belonging systems. The German simulation tool will be exploited repeatedly, in parallel to actual network management, to verify the grid operating conditions for different flexibility management. The Italian simulation environment will be used on-demand, whenever is requested to model and to analyse operating conditions different from the real ones and to assess their impact on the network.

Another relevant difference is related to the scope of the simulation tests, which, in the German case is to perform time-domain quasi-dynamic simulations reproducing the full operating process, considering all the use cases from forecast to optimisation, as it would take place in real operations. In the Italian case, it is to investigate different operating scenarios through static simulations. For these reasons the German simulation tool considers variable time step with a higher resolution of 1 second, while Italian simulations have a fixed time step of 15 minutes (same as the time step used by the SCADA in the real operations).

Besides these differences, which are mainly related to the way simulation are exploited within the demonstration frameworks, the two approaches have also some features in common. They are both including models of OLTCs, considering different DER control schemes, using different load and generation profiles, modeling power and voltage constraints fixed by the upper voltage network (EHV for German case, HV for Italian case) at grid connection points, and performing different scenario simulations with a simple input parameter adjusting.

Concluding, these two approaches are very similar regarding the modelling capability and the application versatility, both being able to carry out a wide variety of analysis; on the other hand, their main differences arise when they are put into the context of their respective demonstration, being developed to cope with specific analysis background and for reaching different goals.

2.3 OPEN QUESTIONS WHICH SHOULD BE ANSWERED BY THE SIMULATIONS

The simulation approaches presented in this document, and the results achieved through their application to the demonstration set-ups can provide valuable information about the exploitation of distributed flexible resources and their impact on the network operating conditions. Considering the demonstrators backgrounds with their specific needs and the corresponding simulation objectives, the simulation test achievements are summarised in the following, for both German and Italian demonstrations.

Within the **German demonstration**, the analysis pursued with the help of the simulation tool allows to determine the impact of flexibility activation from DER in distribution grids on the grid status for different cases.

In detail, simulation results allow to:

- Assess the impact on HV grid with different local reactive power control modes;
- Assess the impact on HV grid optimisation from automatic OLTC in the grid;
- Assess the reaction of HV grid under risk scenarios without DSO optimisation;
- Assess the HV grid status under flexibility provision with DSO optimisation.

Within the **Italian demonstration**, the simulation process allows to evaluate different case scenarios, with an increasing flexible resources availability, assessing the impact of aggregated flexibility exploitation on the network. In detail, simulation results allow to:

- Assess active and reactive power flexibility theoretical ranges and compare them with power exchange at primary substation in normal operations;
- Assess how and in which conditions flexibility exploitation may lead to violations of network constraints;
- Assess how the OLTCs operation may be impacted by flexibility exploitation;
- Assess how different type of flexible assets can contribute to the global flexibility range;
- Assess how the aggregated reactive power capability range changes for different days of the week and seasons of year.

In the following chapters, the simulation approaches and the corresponding tests carried out for German and Italian demonstration are presented in detail, giving a comprehensive description on how the above achievements can be reached.

3. NETWORK SIMULATION FOR THE GERMAN DEMONSTRATOR

This chapter presents the simulation approach and the corresponding tool developed for German demonstrator. As described in detail in Chapter 2, the innovation brought by this simulation approach lies in its functionality and co-simulation capability complying with a remote demonstrator, as well as its potential of application for further grid operation research purposes. In real operation, the simulation tool can be synchronised with the grid control centre, sharing the same data interface and functionality as the original system, performing as a backup and black box (i.e. "digital twin" concept). The grid simulator can be used for the verification of optimisation in the laboratory environment to serve as extra verification tool, and analyse the potential risk under special cases.

The purposes of simulation tests within the German demonstrator are here summarized:

- Verification of grid topology and asset modelling,
- Analysis of impact of different assets' behaviours on the grid status,
- Evaluation of the preliminary optimisation results in the simulation environment.

The preliminary simulation results presented at the end of this chapter give a full functionality verification of the tool itself. Furthermore, the case study gives a deeper understanding of the grid impact of different asset behaviours and the performance of the optimisation tool, which also collects valuable information for the field tests.

3.1 INTRODUCTION

The German demonstrator is mainly developed to optimise the operational conditions in the HV grid of German DSO MITNETZ STROM and to support the upstream grid in enabling provision of available active and reactive power flexibilities. These flexibilities are offered through the EHV/HV grid conjunction points. In the optimisation of the German demonstration, it is considered not to violate distribution grid contingency while flexibilities in distribution grid are activated to solve congestions or voltage violations in transmission grid. The detailed information about available flexibilities in distribution grid are clustered to GCPs and TSO-DSO transformers, so that the TSO gets all necessary information needed for its system operation and at the same time, the amount of information is minimised to meet data thrift goals. The approach of the German demonstration is to enable a stable schedule-based process of congestion management and voltage control in order to address future requirements of system and grid operation, to further integrate variable RES. Therefore, it shows the availability of flexibilities connected to the distribution grid and the needs for coordination between DSO and TSO.

The technical realisation of the German demonstration is based on six system use cases (SUC) (shown in Figure 3.1), described in D6.1 [1]., which are based on two business use cases (BUC) for the German Demonstrator described in D3.3 [1]. These two BUC describing the processes related with the provision of active and reactive power flexibility. The related six SUC are about internal and external communication of demonstrator and DSO control center, optimisation of the distribution grid, an enhanced power system state forecasting to increase the accuracy in the schedule-based processes and the calculation of available flexibilities including the processing of activation requests. Within these use cases, there are several basic functionalities included, like contingency management of distribution grid and state estimation.

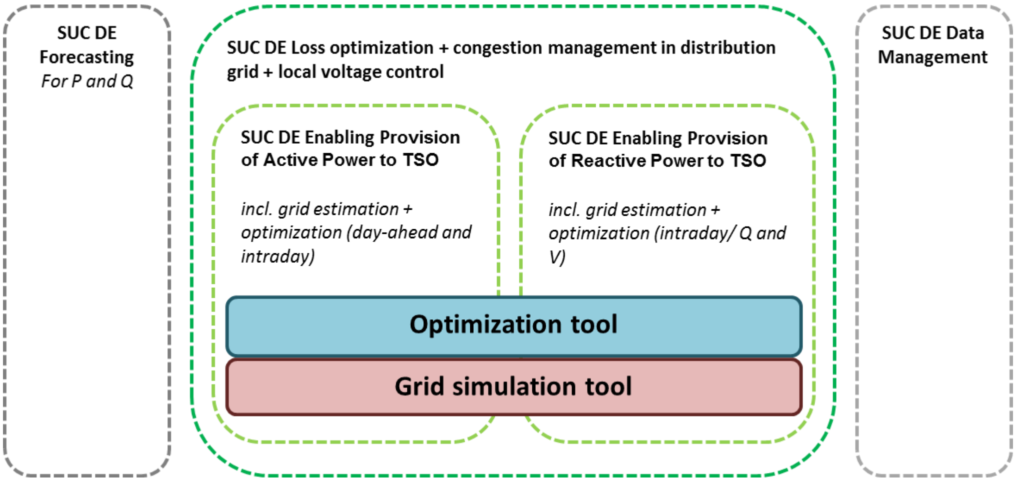


FIGURE 3.1 – USE CASES, FUNCTIONALITIES AND TOOLS RELATIONSHIPS SCHEME IN GERMAN DEMONSTRATION

The observed grid in the German demonstration, with its approximately 6,000 km HV lines, includes more than 11 GW in installed capacity at HV/MV substations and 16 DSO/TSO interconnection points with 40 transformers. The installed capacity of DER exceeds 5.5 GW with over 1,500 units and more than 4 GW in RES. That results in a conservatively estimated range of available reactive power flexibility between -350 MVAr and +280 MVAr. However, this is a reduced reactive power flexibility range, because not all units can be controlled to adjust the reactive power set-point. The not directly controllable units operate at a fixed power factor or according to a defined Q(U) behaviour (droop control). Taking all these requirements and constraints into account, the grid simulation provides an ideal test environment and analysis tool in order to validate the demonstrator's functionalities and analyse their results.

3.2 DESCRIPTION OF THE SIMULATION PROCESS

In the following chapters, multiple aspects of the grid simulation tool of the German demonstration will be introduced. The grid model and components used in the simulation are introduced in chapter 3.2.1 and 3.2.2. The details of modelling grid controller will be discussed in detail in chapter 3.2.3. The scenarios and the time series data to be simulated will be discussed in detail in chapter 3.2.4. A special case study is introduced in chapter 3.2.5.

3.2.1 COMPONENTS OF THE GRID SIMULATOR

To fulfil the objectives described in Chapter 2.3, the grid simulator is scalable and adaptive to meet the requirements of different simulation scenarios. The simulator is designed to perform real-time simulation at a discrete time step of one second, which can also be user defined to a longer time step of 30 s, 60 s, etc. The grid simulator has a modular design, so that the functionality of each component can be developed and tested separately, and stays uncoupled one to the other. Figure 3.2 shows the components and data flow in the grid simulation.

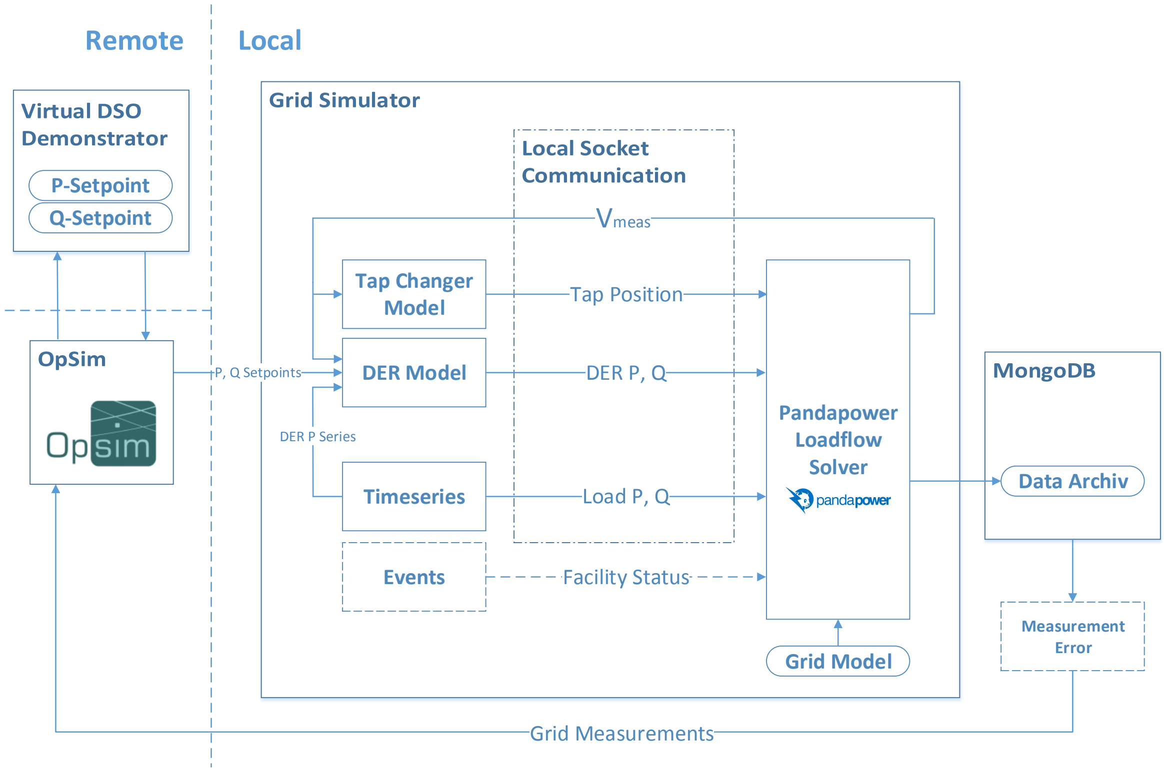


FIGURE 3.2 – SCHEMATICS OF GRID SIMULATION IN GERMAN DEMONSTRATION

Since the goal is to analyse the mid- and long-term stability of the power system, the short-term/transient stability is not in the scope of the simulation and will not be considered. Due to the specific requirements, the grid simulator is mainly designed for quasi-dynamic simulation, in which fast dynamic, frequency deviation and generator angle variation are ignored and assumed already balanced. An extensive analysis of the dynamic behaviour of large transmission system with high penetration of RES is carried out in WP2.

The process of grid simulation can be separated into two parts (remote and local simulation). In the local part of the simulation, the behaviour of equipment will be modelled and the time series and planned events (topology change) will be configured. In order to account for innovative real grid operation aspects, the local behaviour of DERs and the On-Load Tap Changer (OLTC) without any remote control, which can be configured with parameter as it is in the real operation or according to the user defined cases, must be properly modelled in the grid simulation tool. The modelling of DER and OLTC is developed in the Matlab® Simulink®, with the design goal of being adaptive and vectorised, so that with the adaption of initial data the behaviour of N elements is adjusted. The detailed modelling is presented in chapter 3.2.3. Since the grid simulator should simulate the real grid operation under defined scenarios, the simulation is real-time capable. The Simulink® Desktop Real-time™ environment is used for the time synchronisation for the whole simulation.

As power flow solver pandapower [2] (based on Python) is used for the simulation in German Demonstration, which calculates the voltage and load flow in electrical power grid. A significant advantage of pandapower is its standard, open-sourced data structure for the description and modelling of real grids. Since pandapower is built on top of Pandas[1] and an improved Pypower[2] library, it integrates the advantages from both of them, with Pandas offering flexibility in data processing, data exchange in common information format e.g. in JSON format and convenient interfacing to database, while Pypower offers the standard Matpower [3] Bus-Branch modelling. pandapower is a reliable and convenient tool for the power flow-based analysis especially for grid operation and planning. Although pandapower was originally designed for load flow calculation for static grid, in the grid simulator, with the asset modelling in Simulink®, pandapower is also enabled for time-domain quasi-dynamic simulation as the load flow solver. The data communication between Simulink® and pandapower load flow solver is realised by local socket communication as shown in Figure 3.2, which is a common method for highly efficient local inter-process communication.

The process data of the simulation (also simulation results) will be archived in database called MongoDB as key-value pairs at a user-defined rate e.g. every 30 seconds. MongoDB is a popular and high-performance databank (non-SQL) with a flexible document data model. An additional measurement error block can be added to the data flow with the archived data points in MongoDB, so that the common normal-distributed measurement errors of measure equipment can be considered and simulated. Similarly, the events block can be added for given test cases, when topology change and facility status change is required.

In order to enable the online-simulation of the grid simulator with the demonstrator, the communication between remote process and local process is realised by the co-simulation framework named OpSim [4] (shown in Figure 3.3). In which the communication for the real-time/non-real-time simulation of a multi-agent cross platform system can be easily realised. Multiple examples have been already extensively studied in the preceding research projects OpSim and OpSimEval and verified OpSim to be a sustainable and scalable tool for co-simulation in the application field of power grid.

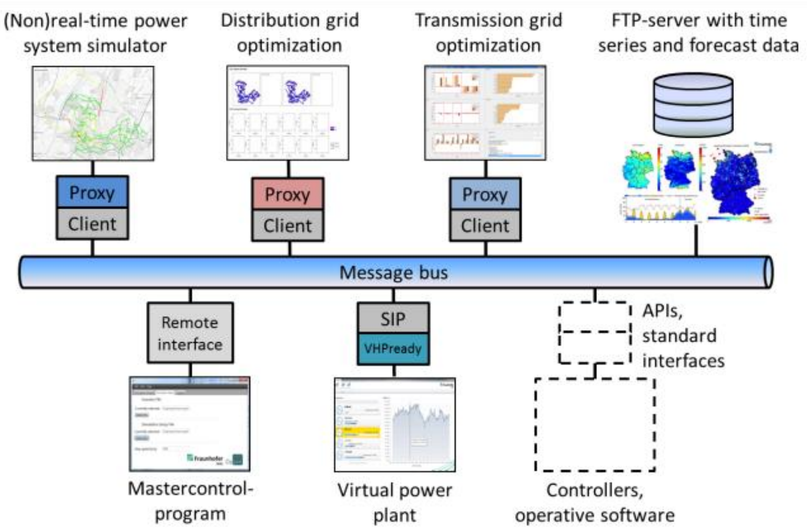


FIGURE 3.3 – SCHEMATICS OF OPSIM COSIMULATION FRAMEWORK

[1] https://github.com/pandas-dev/pandas
[2] https://github.com/rwl/PYPOWER

In the remote process, the laboratory demonstrator will be deployed and tested. The core components and the data flow between the components are shown in Figure 3.4, which are CIM CGMES convertor to pandapower data structure named CIM2PP, State Estimation, Grid Congestion Management and Optimisation.

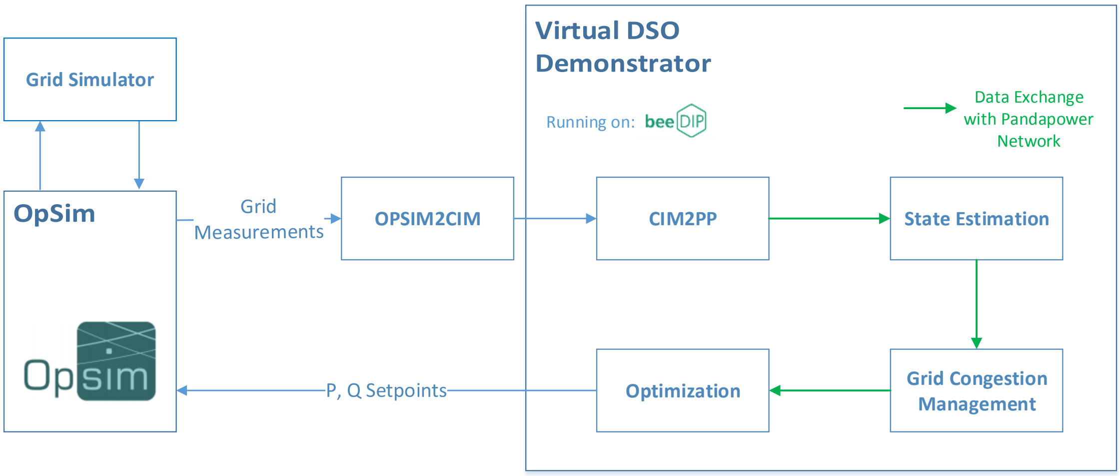


FIGURE 3.4 – CORE COMPONENT AND DATA FLOW IN THE DEMONSTRATION

The demonstrator receives grid models through exchange of standard CIM CGMES Files, which will then be converted to pandapower networks for internal process by the component CIM2PP. The optimisation result (P, Q set-points of DERs) will be transmitted to the grid simulator again through OpSim. The tools in the demonstration are implemented modular and uncoupled. The process chain within the demonstration is realised on the beeDIP [5] platform, which is a platform to integrate different tools for the grid operation originally developed at Fraunhofer IEE (shown in Figure 3.4) and will also be used in the realisation of the field test. The uniqueness of the laboratory demonstrator comparing to the DSO demonstrator is the extra OpSim data convertor (OPSIM2CIM), which exports the required CIM CGMES files based on data from OpSim.

3.2.2 NETWORK DATA

The simulation objects of the German demonstration are the HV and aggregated MV grids from the DSO MITNETZ STROM. Mitnetz is a distribution system operator (DSO) in Eastern Germany with the responsibility of operating HV, MV and LV level grids across parts of the three federal states: Brandenburg, Saxony, and Saxony-Anhalt. The grids in Saxony are divided into two grid regions (West Saxony and South Saxony). The four grid regions - Brandenburg, West Saxony and South Saxony, Saxony Anhalt – are normally operated unconnected, and only coupled through the EHV grid operated by the TSO (50Hertz). The HV grid (110kV) of Mitnetz is characterised by their high DER infeed, especially in the grid region Brandenburg and Saxony-Anhalt. In 2018, the RES integrated in the Mitnetz grid presented a total installed capacity of 8.87 GW, which includes over 4.8 GW wind, around 3.5 GW solar, 0.33 GW biomass, 85 MW hydro and 13 MW others, according to the official numbers from Mitnetz,. The local grid has already a DER/load ratio of 104% in annual mean. A geographical grid map with lines, where congestion has occurred at some specific moments, is shown in Figure 3.5. As can be seen in the grid map, in order to be able to deliver flexibility from local DER to the EHV Grid, the frequent appearance of local grid congestion must also be taken into consideration.

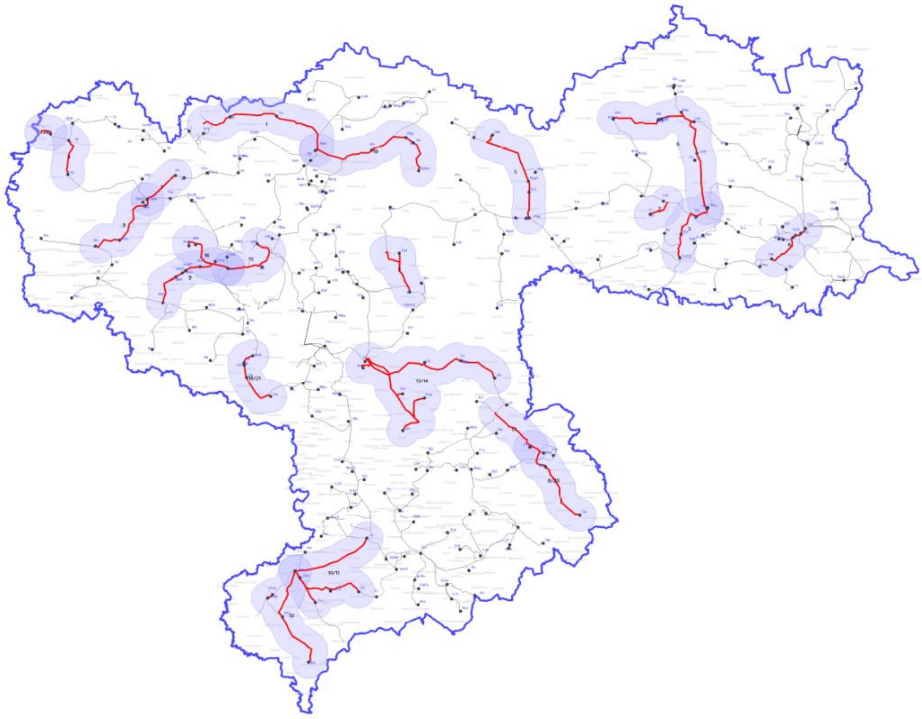


FIGURE 3.5 – GRID MAP WITH THE LINES WHERE LOCAL CONGESTION OCCURED IN MITNETZ HV GRID (SOURCE: MITNETZ [6])

The basic information of the local grid conjunctions to the EHV grid of TSO 50Hertz is listed in Table 3.1

TABLE 3.1 – GRID PARAMETERS IN THE SIMULATION

	Subnet 1	Subnet 2	Subnet 3	Subnet 4
Name	West Saxony	South Saxony	Brandenburg	Saxony-Anhalt
Number of Grid Conjunction Point	3	6	4	3
Number of EHV-HV Transformer	7	13	10	10

Mitnetz delivered the grid data in the format of CIM CGMES files (for details please refer to [7]) as shown in Figure 3.6. The real time series are delivered by DSO Mitnetz directly as standard CIM CGMES files, which provide snapshots of the grid every 15 minutes. The CIM CGMES files are converted to pandapower networks, so that it can be conveniently converted to time series required in Simulink (Matlab® time series format) with existing tools. The state estimation module in pandapower is used to exclude possible interpretation errors in grid modelling and to get more accurate state data from the measurements. The CIM CGMES file has resolutions of 5 - 15 minutes, and the time series will then be interpolated to a higher resolution (about 1 second for the simulation). At one time step, all four existing grid regions at Mitnetz will be delivered in one set of CIM CGMES files. EHV grids (transmission lines) between grid regions and to external grid regions are disconnected, which are modelled in CIM as substitute PQ-load. Each grid region has its own voltage reference node (slack node).

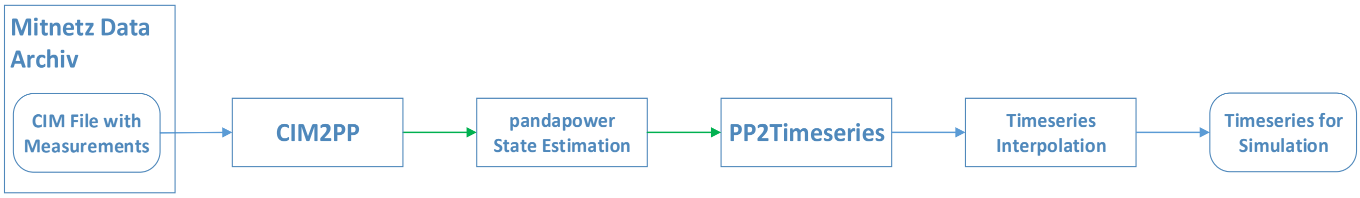


FIGURE 3.6 – DATA PROCESSING OF REAL TIME SERIES

For the grid simulation, following generated time series and real time series are used:

1. Variable day case (generic time series);
2. Voltage collapse on 24th of October 2018 (real time series).

The variable day case was created based on one snapshot of the grid state. In this snapshot, the consumption and generation in the HV- and MV-grids (aggregated loads and the DER) vary between zero and the observed value randomly; the EHV grid is considered to be constant in this case. Time series with randomly generated grid states are generated this way and are designed to simulate the HV grid state under large variation.

3.2.3 ALGORITHMS AND MODELLING

In the grid simulation, the grid topology is modelled static (influence of parameters from temperature and transient process will be neglected) and following equipment behaviour are considered:

1. Active and reactive power of DERs;
2. Tap switching of OLTC transformer.

Since the simulations are carried out in quasi-dynamic manner, the load dynamics e.g. dynamic behaviour from large electrical machines and generators are considered to be already outbalanced and hence being constant.

MODELLING OF DER

With increasing number of connected DERs to the MV and HV Grids, the grid simulation needs to consider the behaviour of DERs under decentralised control and central DSO optimisation. On the Mitnetz HV grid, the DERs including large Wind and PV parks are the focus of the simulation, since they are also the main source of the flexibility within the project scope. In order to model the DERs for quasi-dynamic simulation, a simplified dynamic DER model is developed. The internal state is assumed to be constant, and the active power and reactive power are directly available at the grid interface.

In the real grid operation, the active power of the DERs (mostly non-synchronous machine, e.g. PV and Wind parks) is mostly limited by the availability of wind and solar irradiance and, if no grid congestions and without planned or unplanned outage, DERs will maximise the active power injection as they can. The reactive power modes of the DERs in the simulation are listed in Table 3.2.

TABLE 3.2 – DESCRIPTION OF REACTIVE POWER MODE OF DERS IN THE SIMULATION

Mode name	Q Behaviour	DSO Optimisation
Q0	Q=0, no reactive power injection	Not available
Cosphi	Fixed Power factor (PF) = 0.95, capacitive	Not available
QU	Infeed Q according to the Q(U) curve	Q(U) curve can be remote controlled
Remote control	Remote Q set-point	Set-point can be remote controlled

In the simulation, the following Q modes are considered: Q0, Cosphi, QU and remote control. Q0 represents the mode where no reactive power is being injected; Cosphi stands for an operation with a fixed power factor; QU describes reactive power provision according to a defined Q(U) droop-curve and remote control means providing reactive power according to a direct received Q set-point. All the DERs will be allocated with one of the reactive power modes. Q0, Cosphi and QU are the Q modes for the DERs in the analysis of decentralised reactive power control. The remote setting of Q(U)-curve as listed in Table 3.2 is not considered in the simulation in current phase and thus disabled. Remote control mode is automatically activated when a Q set-point is given. The complete DER model is shown in Figure 3.7.

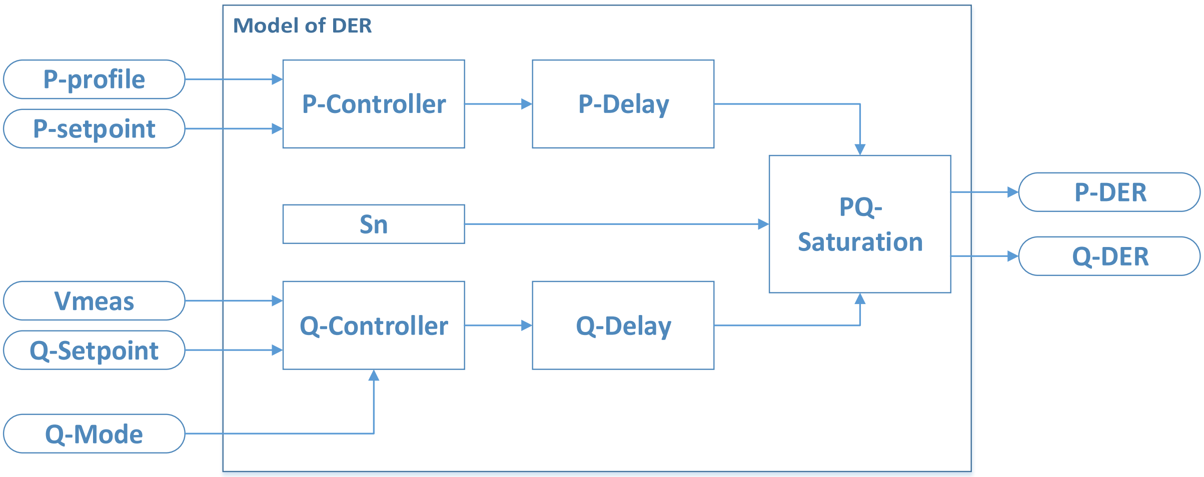
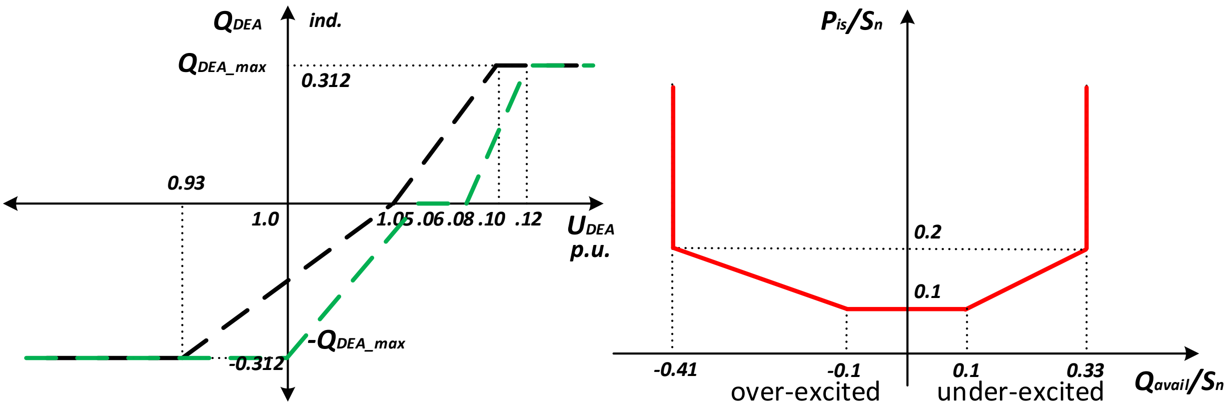


FIGURE 3.7 – SCHEMASTICS OF DER MODELLING IN GERMAN DEMONSTRATION

The DER model consists of following blocks: a P-Controller and P-delay block for the PT1[3] behaviour, Q-Controller with mode selector and Q-delay block, PQ-saturation. The P-profile here defines the availability of the active power. If the P set-point is given, the DER will follow the P set-point without exceeding the P-profile. Else, the DER will infeed active power according to P-profile. As for the Q-controller, modes Q0 and Cosphi are common for older DERs, the reactive power is unrelated to the grid situation (voltage) at the grid connection point. The new DERs will operate under mode QU, which means that voltage at the grid conjunction point is essential for the decentralised Q control. Static Q(U)-curve for the Q-droop control under QU-mode is shown in Figure 3.8a, the DERs are able to stabilise the voltage to given voltage set point e.g. 1.05p.u. for the black line and 1.07p.u. for the green line.

[3] Describes the adjustment behaviour of a DER if a direct set-point is given

The PQ-saturation block saturates the P, Q capability of DERs under different working points and calculates the invertor active power losses. The reactive power available range is shown in Figure 3.8b, which is related to the P availability and the DER installed capacity. When P is below 10% of the DER installed capacity, no reactive power will be available. The modelling will be verified, and the result will be visualised in chapter 3.3.1.



a) Q(U)-characteristic curve b) Q working range

FIGURE 3.8 – A) DER Q-U CONTROL CHRACTERISTICS AND Q WORKING RANGE; B) Q WORKING RANGE OF DER

MODELLING OF TRANSFORMER TAP CONTROLLER

The OLTC at the HV/MV transformer in the distribution grid is essential for the voltage control and voltage stabilisation. In the grid simulation of the German Demonstration, the real-life behaviour of the OLTC is modelled for evaluation purpose. In the Mitnetz grid, all HV/MV transformers are equipped with automatic voltage controller and OLTC as shown in Figure 3.9.

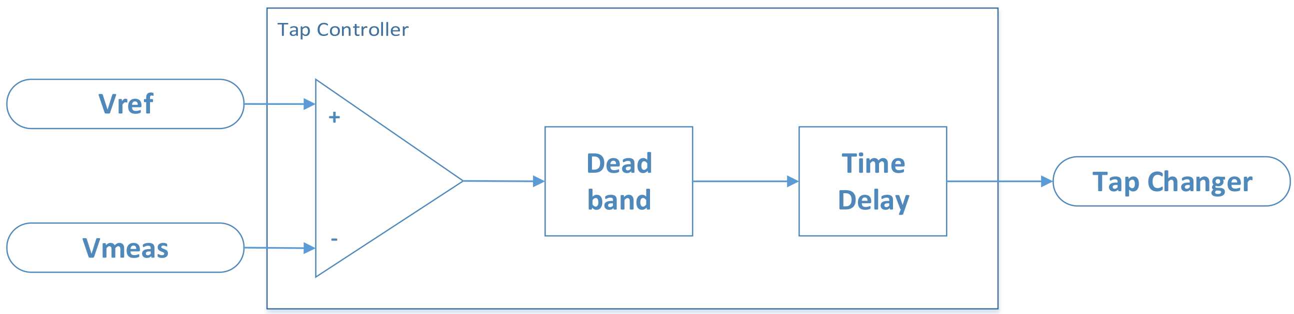


FIGURE 3.9 – MODELLING OF THE TRANSFORMER TAP CONTROLLER

A tap change action will be triggered when the voltage at the control bus exceeds the predefined allowed voltage band. For simulation purpose, the allowed voltage band is defined as 0.95 to 1.05 p.u. with the transformer's lower-voltage side bus defined as control bus. The focus of the simulation is to study the impact of automatic OLTC on the meshed HV grid, since the MV grid in the Mitnetz is not modelled in detail for the German demonstration.

In the Mitnetz grid, the change of the tap position of the EHV-HV transformer will only take place through manual contact (mainly by telephone contacts) between the grid control centres of the both system operators. It requires the approval of both operators according to their own grid conditions, in this case DSO Mitnetz and TSO 50Hertz.

From the historical point of view, this action took place very rarely (once for a couple of days, or by planned transformer switching), so the tap position of EHV-HV transformers will be considered unchanged during the simulation.

3.2.4 DESCRIPTION OF THE SIMULATION SCENARIOS

With the available data and grid modelling, different simulations can be performed as shown in Figure 3.10. In this picture, simulation types to be carried out in the German demonstration are defined. For the development of the grid simulator, modules must be verified individually, which includes the validation of the static grid model, quasi-dynamic modelling and the internal data flow. The static grid model will be verified with the measurements recorded in the CIM CGMES-file and the result from state estimation tool the asset modelling will be validated with the anticipated behaviour with the visualisation of the simulation process data.

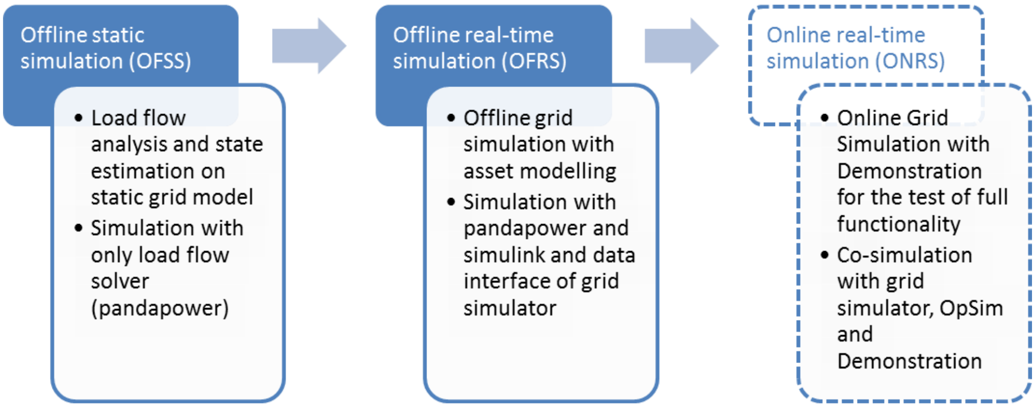


FIGURE 3.10 – SIMULATION TYPES OF THE GERMAN DEMONSTRATION

Different simulations with representative real time series named “voltage collapse” in addition to the variable time series are performed and results are presented in this deliverable. The DSO Mitnetz is located at the transmission path between the windy area in the North and the main energy demand in the South of Germany. The capability of activating flexibility from the local grid will provide an interesting feedback for other European areas with similar high penetration from DER, and suffering from global congestion because of the limitation in transmission capacity and relevant grid safety and stability issue. In this deliverable, the process and results of OFSS and OFRS will be presented. The results of the ONRS, which require the full functional demonstration, will be presented in deliverable D6.7. Table 3.3 shows the simulation scenarios to be analysed in this deliverable. The two time series to be simulated are defined as the following: *TS Var* for the variable time series*, TS Col* for the voltage collapse time series.

TABLE 3.3 – SIMULATION OVERVIEW IN THE GERMAN DEMONSTRATION

Simulation Type	Test Time Series	Test Purpose
OFSS	TS Col	Validation of Grid topology and state estimation tool
OFRS	TS Var	Validation of modelling of DER and OLTC
OFRS	TS Var / TS Col	Local grid analysis and voltage profile analysis
OFRS	TS Col	Verification of results from DSO optimisation

3.2.5 SCENARIO VOLTAGE COLLAPSE ON EHV GRID IN OCTOBER 2018

A reference event which occurred on the 24th of October of 2018 was delivered by Mitnetz for the grid simulation. Because of a high loading rate in an EHV transmission line, the TSO requested NCM (Network Congestion Management), in which multiple DERs (mainly large wind parks) in the DSO grid were requested to shut down or curtail their infeed power, on the Mitnetz GCP Lauchstädt in the grid region Saxony-Anhalt. The NCM began at around 10:30 AM[4] and lasted for more than four hours. The NCM was requested to solve the congestion on the transmission line between grid stations Lauchstädt and Vieselbach, as the line loading marked in Figure 3.11, implies. As a result, the voltage of the EHV and HV grid has dropped almost to the security margin because of the lack of reactive power flexibility or the lack of mechanism to utilise the reactive power flexibility. This situation is interesting to analyse since solving this critical situation could have been greatly supported with the help of the German demonstration functionalities by the DSO Mitnetz.

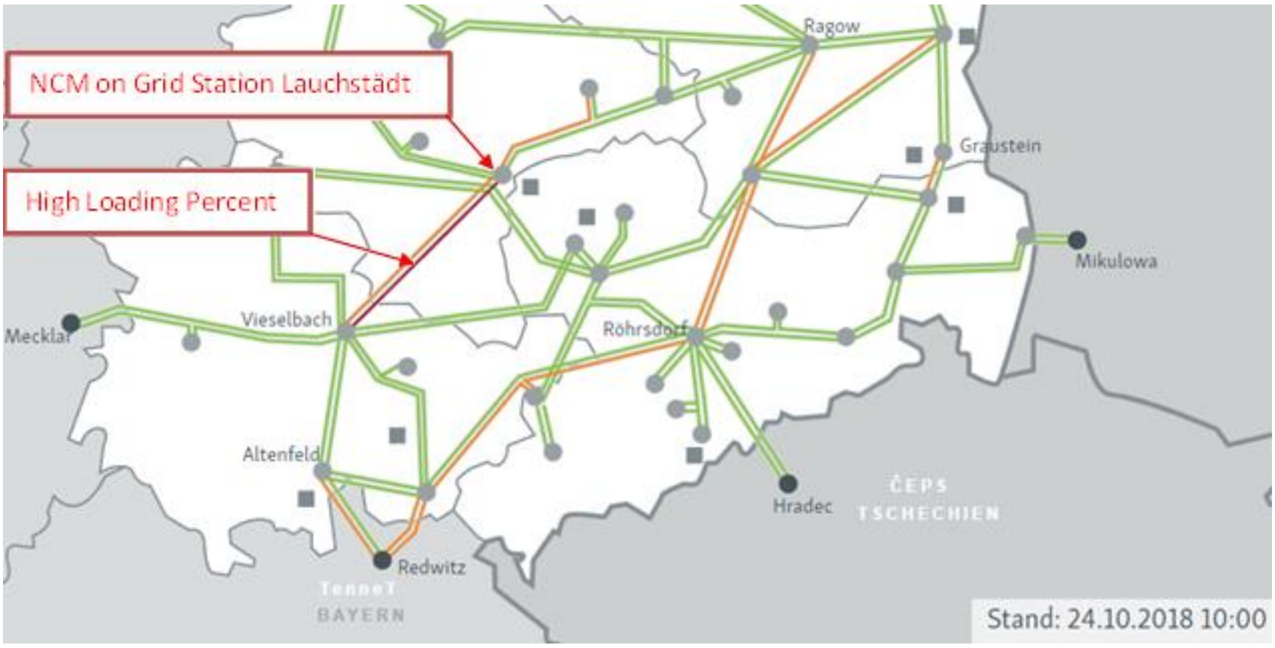


FIGURE 3.11 – GRID SITUATION OF EHV GRID ON 24.10.2018 (SOURCE: 50HERTZ [8])

As Figure 3.12 shows, the infeed to the EHV grid from the HV grid was reduced at the GCP Lauchstädt in two steps, with the first one shortly before 11:00 AM and the second one shortly before 12:00 AM (marked NCM in Figure 3.12). Shortly before 12:00 AM, the voltage of the EHV grid dropped to 390 kV, while normally the voltage should be stabilised at around 400 kV, which is shown in Figure 3.13. Although the NCM was requested at the GCP Lauchstädt, the transmission power from Lauchstädt to Vieselbach kept increasing from 10:00 AM to 12:00 AM because of high availability of wind in the north of Germany at this time (as shown in Figure 3.14). With the voltage in the transmission system decreasing, the current on the congested overhead transmission line kept increasing. As a result, an increasing need of reactive power in the transmission system was caused and finally

[4] German Berlin time (UTC+2)

lead to the voltage collapse below the lower voltage band limit because no reactive power compensation could be activated.

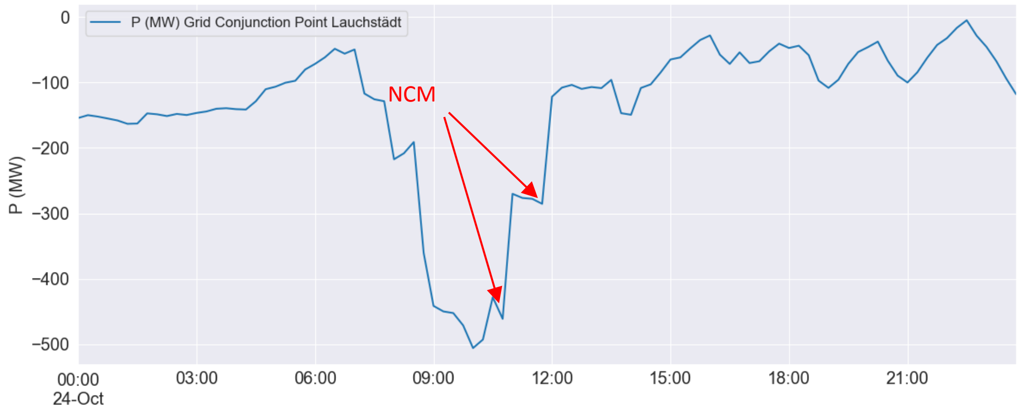


FIGURE 3.12 – GRID EXCHANGE EHV-HV AT LAUCHSTÄDT IN CASE VOLTAGE COLLAPSE

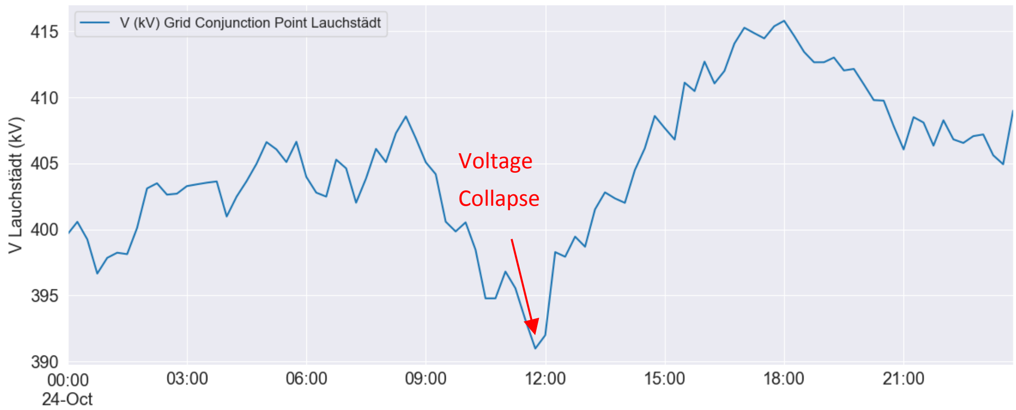


FIGURE 3.13 – EHV VOLTAGE PROCESS AT LAUCHSTÄDT IN CASE VOLTAGE COLLAPSE

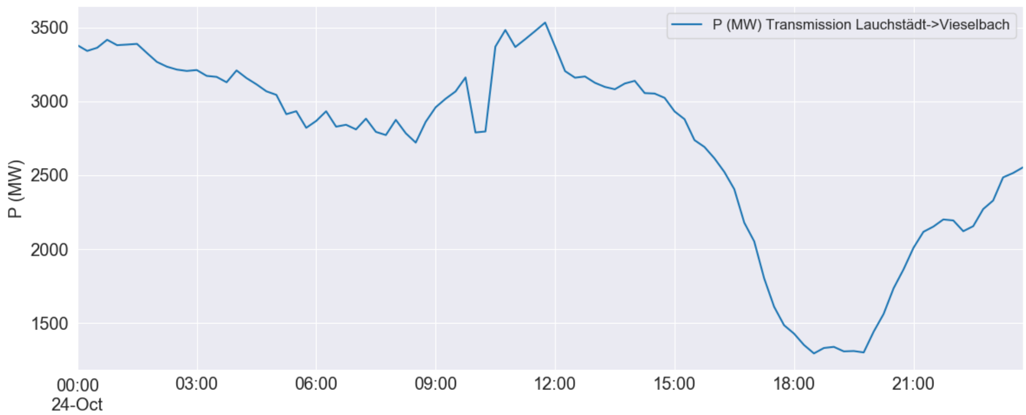


FIGURE 3.14 – TRANSMISSION POWER LAUCHSTÄDT TO VIESELBACH IN CASE VOLTAGE COLLAPSE

The sensitivity of DERs in the HV grid region connected to substation Lauchstädt and the comparison of the situation before and after the NCM is shown in Figure 3.15. Since multiple DERs were completely shut down, they lost their availability for reactive power contribution. Nevertheless, all DERs in that region have sensitivity to support voltage at GCP Lauchstädt as shown in Figure 3.15a. Hence, the assumption can be made that there would had been still enough reactive power flexibility in the DSO grid to support voltage at GCP. Many DERs in the grid region Saxony-Anhalt were still in-feeding active power and therefore available for reactive power provision, as shown in Figure 3.15c, but they were not in-feeding capacitive reactive power for the voltage stabilisation as shown in Figure 3.15d during the time of this incident. A coordinated or decentralised utilisation of reactive power flexibility could have helped to avoid or even minimize the voltage collapse in this case. It is noticeable at this point, that generally the DERs have much higher sensitivity to the grid where they are connected (here HV) than to the upstreaming (here EHV) grid. This is shown in Figure 3.15a and Figure 3.15b, so the local voltage is assumed to be a main limit to exploit local reactive power flexibility for the upstream voltage level. As a conclusion, the grid simulation focuses on this case considering DSO optimisation of distributed flexibilities and decentralised reactive power control to see if the local DERs could have helped solving the voltage collapse.

FIGURE 3.15 – A) VOLTAGE SENSITIVITY TO EHV GRID FROM ALL DERS IN MITNETZ HV GRID SAXONY-ANHALT
B) VOLTAGE SENSITIVITY TO HV GRID FROM ALL DERS IN MITNETZ HV GRID SAXONY-ANHALT
C) P-INFEED OF ALL DERS IN MITNETZ HV GRID SAXONY-ANHALT BEFORE AND AFTER NCM
D) Q-INFEED OF ALL DERS IN MITNETZ HV GRID SAXONY-ANHALT BEFORE AND AFTER NCM

3.3 SIMULATION RESULTS

In this section, the results of the grid simulation of the German Demonstration are presented. Chapter 3.3.1 presents the result of state estimation and the behaviour of asset model. Chapter 3.3.2 shows the result of the simulation of *TS Var* on the Mitnetz grid to analyse the impact of OLTC and general impact from different Q-modes to the Mitnetz grid. Chapter 3.3.3 shows the results of the case study “voltage collapse”, which is carried out, firstly with DSO optimisation, and secondly with decentralised Q control.

3.3.1 GRID TOPOLOGY AND MODEL VALIDATION

In this section, the result of OFSS with *TS Col* is presented. To verify the functionality of the CIM2PP tool as stated in Figure 3.6, which converts the static CIM CGMES grid to pandapower networks, the state estimation tool from pandapower is utilised. The state estimation tool in pandapower implements the weighed least square (WLS) algorithm. After successful state estimation, the resulted voltage profile of HV and MV grid are compared against the original measurement. The measured and estimated voltage of the three buses on EHV and HV grid and the residual of the measurement and estimation are shown in Figure 3.16. The residual distribution is shown in Figure 3.17.

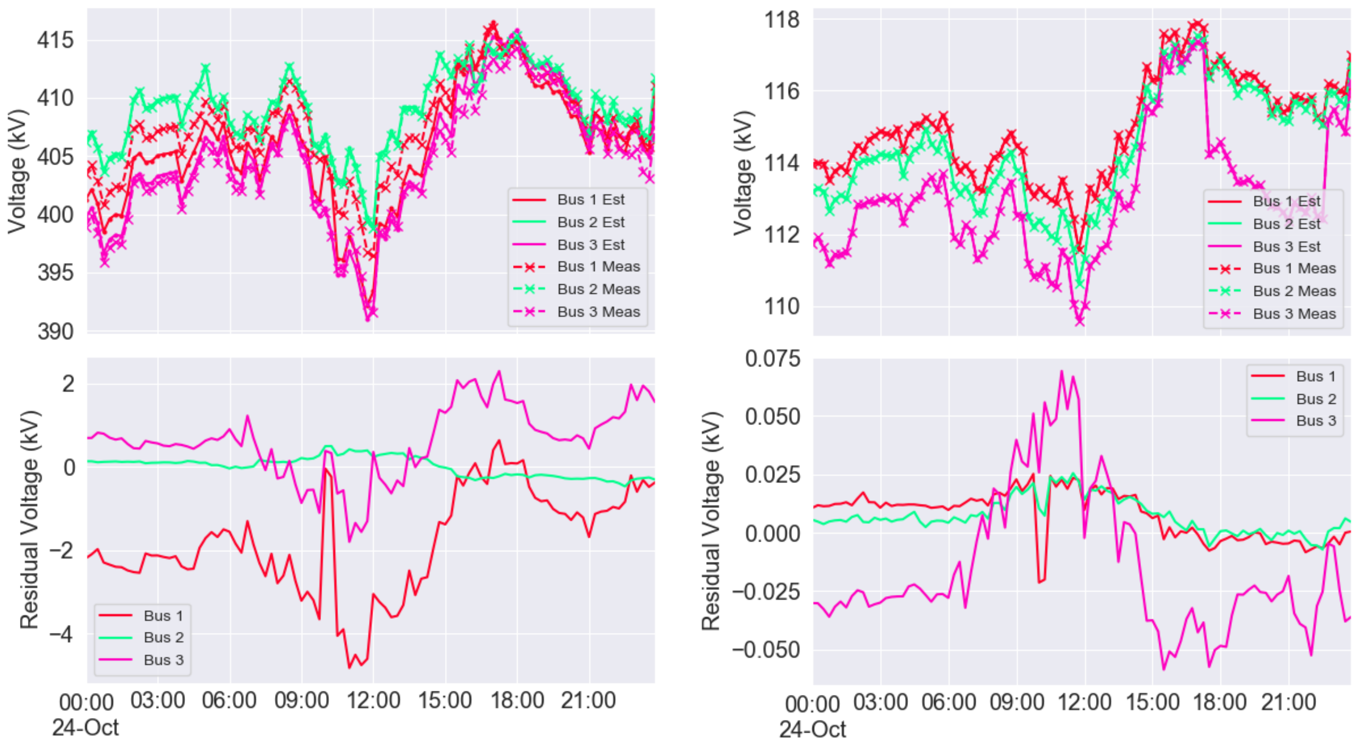


FIGURE 3.16 – VOLTAGE PROCESS IN THE CASE “VOLTAGE COLLAPSE”

In Figure 3.16 it can be seen that on the selected EHV bus, the voltage difference between the estimated and the measurements are larger than those of the HV grids are. This is also implied by the distribution of residuals in Figure 3.17. This behaviour is caused by the simplified EHV grid modelling, since the external EHV grids with respect to each grid region are simply modelled as substitute loads. Compared to the HV grid, this reduces the measurements redundancy of the EHV grid. Generally, the residual voltages are in a reasonable range and correspond to the accuracy of the used measurement devices which show a standard deviation in voltage of about 0.5%. Hence the functionality of CIM2PP converter and the accuracy of the grid modelling can be verified.

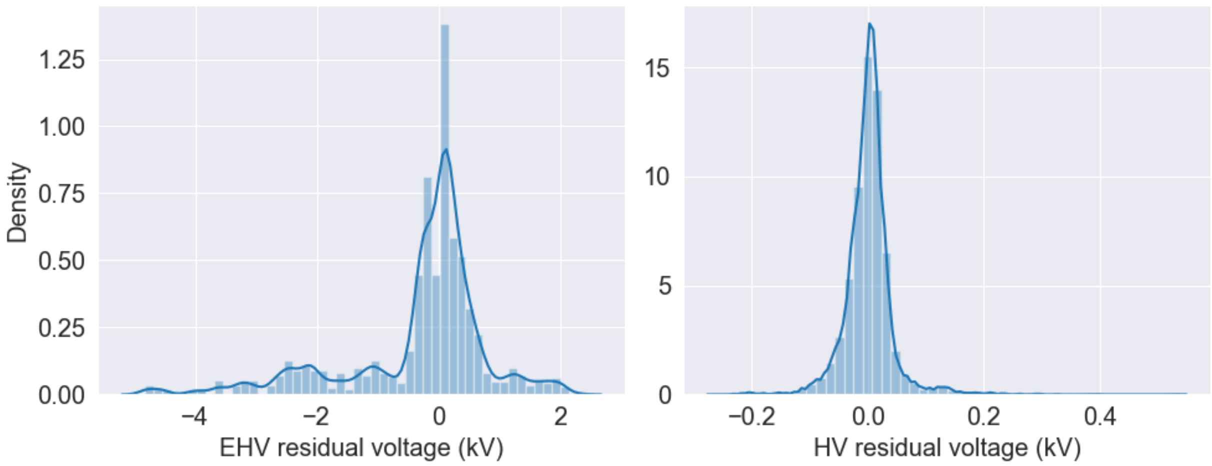


FIGURE 3.17 – DISTRIBUTION OF RESIDUAL VOLTAGE BETWEEN ESTIMATION AND MEASUREMENTS

From OFRS with *TS Var*, the results of the reaction of DER to the local voltage and the reaction of the OLTC with the example of one of DER and tap changer is shown in Figure 3.18. Figure 3.18a shows that when using a voltage set point of 1.05 p.u., the DER will infeed inductive reactive power (in the figure negative Q) when the voltage is higher than 1.05 p.u.. This behaviour can be observed within the reactive power availability according to the active power availability and is proportional to the voltage deviation. Figure 3.18b shows the reaction of the tap changer when a voltage violation occurs at t = 50 s of the simulation timeline. The tap changer reacts after a short dead time after the voltage violation occurrs as marked in the Figure 3.18b. The voltage violation is solved by down tapping. With this result, it can be verified that both DER model and OLTC are functioning as expected.

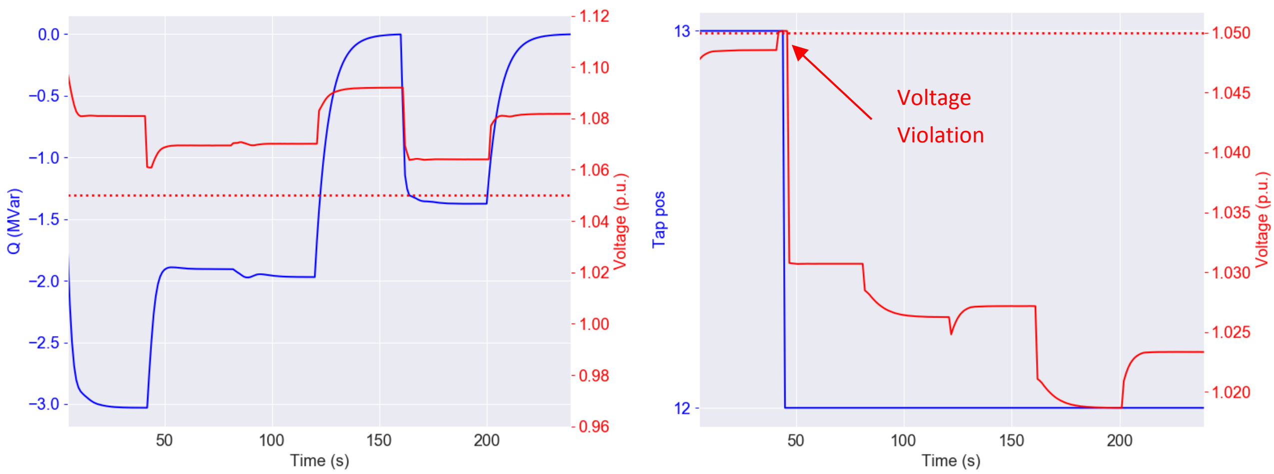


FIGURE 3.18 – A) EXAMPLE BEHAVIOUR OF DER (LEFT); B) EXAMPLE BEHAVIOUR OF TAP CHANGER (RIGHT)

3.3.2 ANALYSIS WITH MANUALLY GENERATED TIME-SERIES

In this section, OFRS with *TS Var* are performed and the results are presented. In the mode OFRS, the process data is stored in MongoDB, with which the analysis is conducted. The main purpose of the simulation is to investigate the voltage profile at local grid under different Q modes of DER and with or without activation of automatic OLTC. Eight scenarios of different control modes of DERs and HV/MV transformer tap controllers are simulated, as listed in Figure 3.4.

TABLE 3.4 – SIMULATION SCENARIO DESCRIPTION FOR TS VAR

Scenario name	Q control mode (see Table 3.2)	Automatic OLTC
Case 1	Cosphi	Deactivated
Case 2	Q0	Deactivated
Case 3	QU (voltage set-point 1.05p.u.)	Deactivated
Case 4	QU_cosphi (Large DERs (>20 MW) as Case 3, Small DERs (≤ 20 MW) as Case 1	Deactivated
Case 1_auto	Cosphi	Activated
Case 2_auto	Q0	Activated
Case 3_auto	QU (voltage set-point 1.05p.u.)	Activated
Case 4_auto	QU_cosphi (Large DERs (>20 MW) as Case 3_auto; Small DERs (≤ 20 MW) as Case 1_auto	Activated

In Figure 3.19, the sum of reactive power from all DERs in all four grid regions of Mitnetz grid is shown for the different cases, the cases of both OLTC modes. Major differences of the reactive power of the DERs between the scenarios can be observed. In “Case 1+Case 1_auto” (case 1 (blue line) and case 1_auto (red line) exactly overlap in Figure 3.19), maximum capacitive reactive power is injected into the grids for the purpose of voltage support. In “Case 2+Case 2_auto” (exactly overlapping in Figure 3.19) zero reactive power is observed. In “Case 3+Case 3_auto”, adaptive reactive power is observed. In “Case 4+Case 4_auto”, higher reactive power as in “Case 3+Case 3_auto” can be observed, since small DERs are in-feeding maximum reactive power.

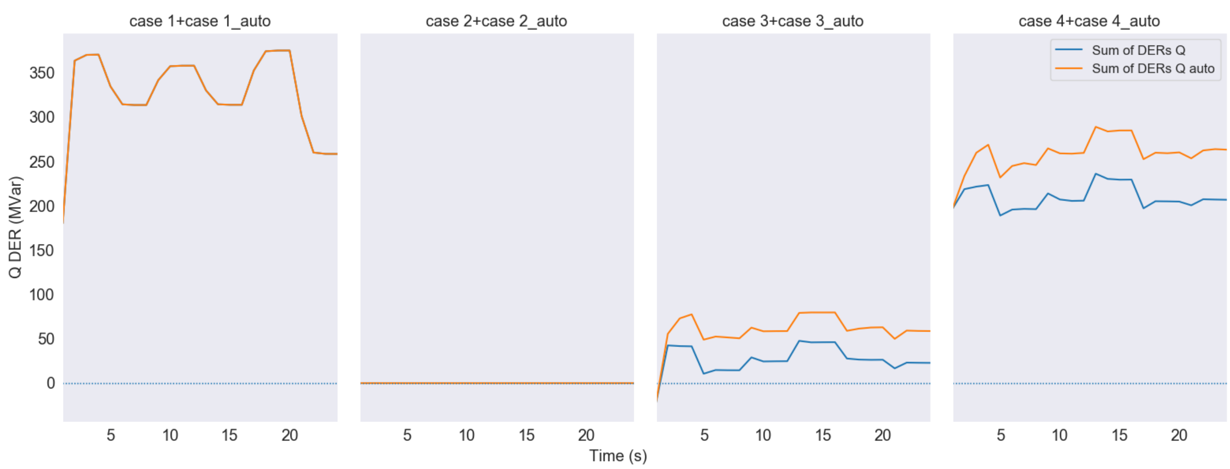


FIGURE 3.19 – SUM Q OF DERS IN DIFFERENT SCENARIOS

The voltage profiles of the MV grid are shown in Figure 3.20 as boxplot (with the x-axis representing the time in the simulation). With an automatically tapping OLTC at the HV/MV transformer (case x), the voltage profiles of the MV buses are much more stable and concentrated around 1.03p.u. compared to the scenarios without an automatically tapping OLTC (case x_auto). The influence of the different reactive power modes on the voltage in the MV level is observable when comparing “Case 1”/“Case 1_auto” with “Case 2”/“Case 2_auto”. The medium and the highest voltages of “Case 1”/“Case 1_auto” are slightly higher because the DERs infeed with maximum reactive power at a fixed cos(φ) in “Case 1”/“Case 1_auto” compared with no reactive power infeed in “Case 2”/“Case 2_auto”. This is possibly because DERs connected to the MV grid are simplified and not modelled in the simulation.

The voltage profile of all HV buses in the Mitnetz grid is shown in Figure 3.21 as boxplot (with the x-axis representing the time in the simulation). The medium values of the voltages at the HV buses in “Case 1”, “Case 4”, “Case 1_auto”, “Case 4_auto” are generally higher than those in “Case 2”, “Case 3”, “Case 2_auto”, “Case 3_auto” respectively, which matches also the reactive power infeed of each case. Thus, reactive power infeed from DERs has apparent influence on HV voltages.

Automatic OLTC also affects the HV voltages. Comparing “Case 1” and “Case 1_auto”, both the MV voltage and HV voltage are more concentrated around 1.03 p.u.. Similarly, for “Case 3” and “Case 3_auto”, the medium values remain basically unchanged, but the distribution in “Case 3_auto” is more concentrated. In the other four cases, no major difference of the distribution of HV voltage according to the status of automatic OLTC can be observed. Concluding, the automatic OLTC has generally more impact on the MV voltage as of the HV voltage.

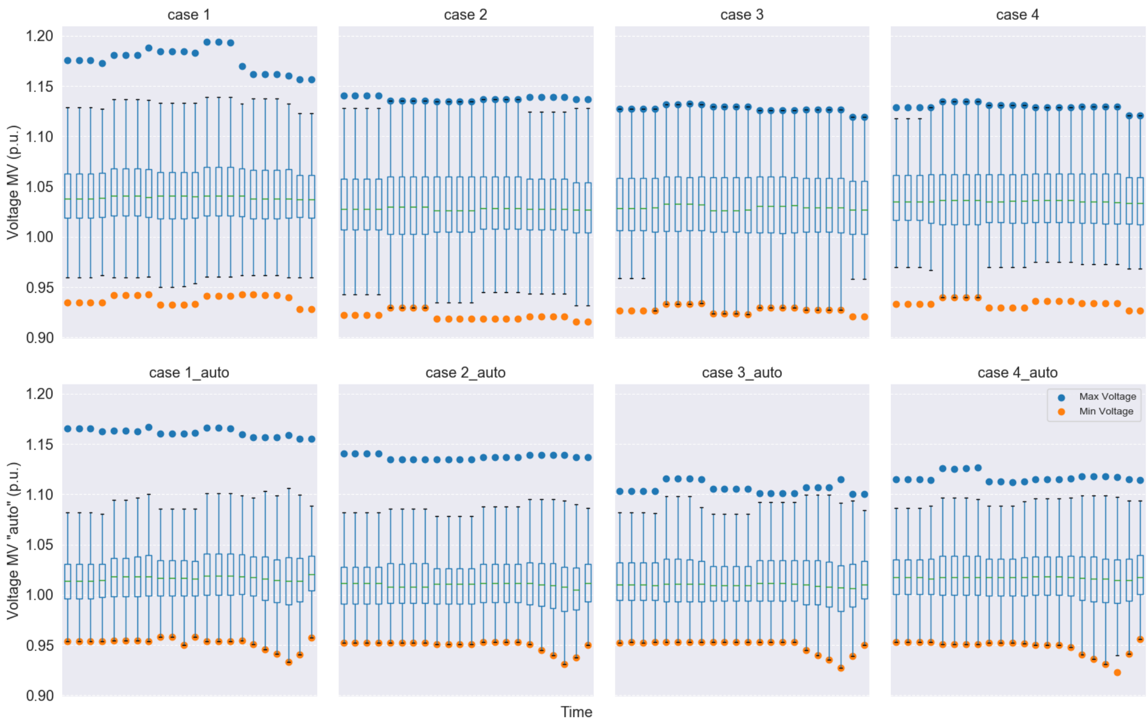


FIGURE 3.20 – VOLTAGE PROFILES OF ALL MV BUSES IN DIFFERENT SCENARIOS

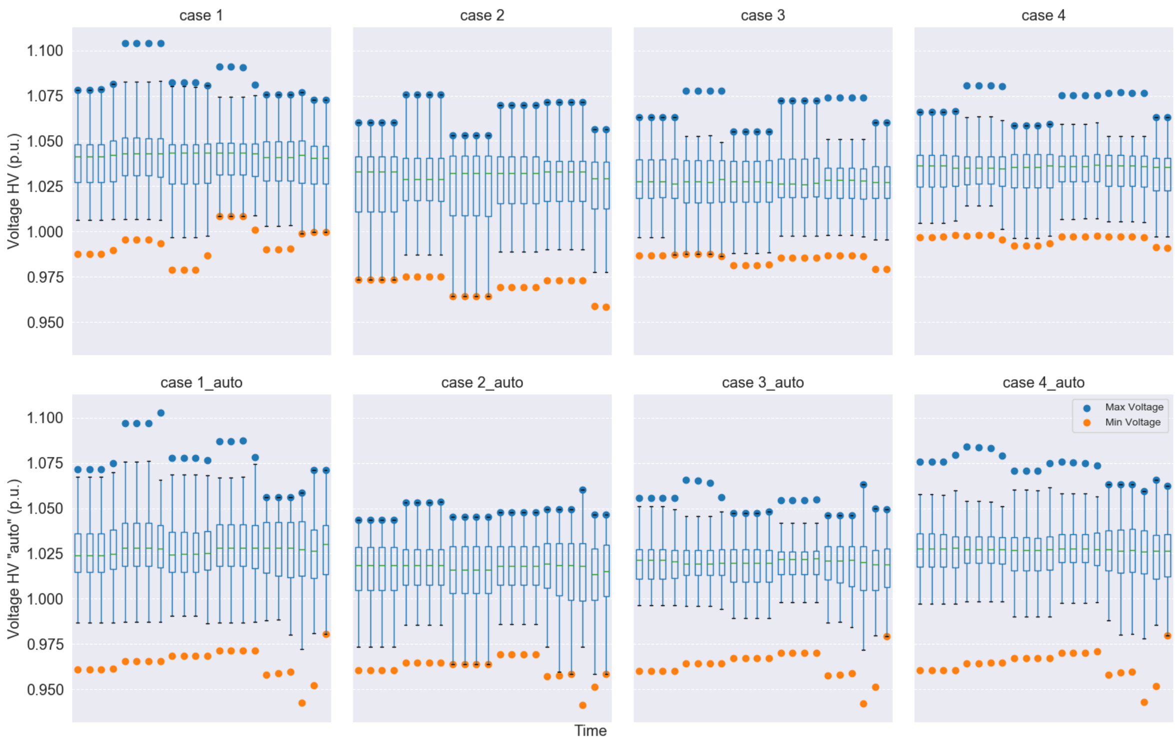


FIGURE 3.21 – VOLTAGE PROFILE OF ALL HV BUSES IN DIFFERENT SCENARIOS

In the above section the simulation results from the OFRS with *TS Var* under different reactive power modes and OLTC on/off status are presented. As a conclusion it becomes clear that with different reactive power modes of the DERs, different amounts of reactive power are injected to the grid, which has apparent influence on the HV grid voltage. The impact on the MV voltage is comparatively less because of the lack of DER modelling connected to the MV grids. Automatically tapping OLTCs are essential in keeping the MV voltage within the range of voltage limits and partly uncouple MV grids from HV grids (voltage wise). Their impact on voltage in the HV level is limited though.

3.3.3 CASE STUDY "VOLTAGE COLLAPSE"

In this section, the simulation results of the *TS Col* as introduced in section 3.2.4 are presented. The main purpose of this case study is to analyse the influence of reactive flexibility use on the grid region Saxony-Anhalt of Mitnetz comparing flexibility optimisation by the DSO and flexibility use under decentralised control with the scenario of no reactive power flexibility use.

SIMULATION WITH FLEXIBILITY OPTIMISATION BY DSO

In order to simulate the scenario with optimization offline, the optimisation is performed separately. OFRS of the *TS Col* with the data interface to OpSim is performed. Optimisation was carried out onto the 15 minutes grid status snapshot from Mitnetz, Q set-points for the DERs of the voltage collapse case can be calculated and archived for the usage in the simulation. The optimisation goal is set as stabilisation of the EHV voltage at Lauchstädt to 402 kV. The calculated Q set-points will be sent to the grid simulator during the simulation through the dedicated data interface of OpSim. The simulation scenarios covered are listed in Table 3.5.

TABLE 3.5 – SIMULATION SCENARIO DESCRIPTION FOR TS COL WITH FLEXIBILITY OPTIMISATION BY DSO

Scenario name	P Time series	DER Q Mode
Orig	Original	Original Q time series
Opt	Original	Q set-points from DSO optimisation

The results of the simulation over time are shown in Figure 3.22, Figure 3.23, Figure 3.24 and Figure 3.25. “Orig” and “Opt” indicate the original result and the result with a flexibility optimisation by the DSO respectively. In scenario “Orig”, the voltage process as shown in Figure 3.13 is recreated (as shown in Figure 3.23). In Figure 3.23 it can be observed that the voltage at the GCP Lauchstädt and local grid are much more stable in scenario “Opt” than in scenario “Orig”, although the slight delay due to communication and variation of grid state causes some oscillations. From Figure 3.24 it becomes clear, that the voltage of the HV grid can be kept within the allowed limits in scenario “Opt” except for a few moments. Regarding the line loading, which is shown in percentage in Figure 3.25, both scenarios “Orig” and “Opt” show that the maximum loading percent of the lines stays under 100% for the (N-0)-case and no major differences can be observed between them.

From these results, it can be concluded that with the flexibility optimisation by the DSO, the local reactive power flexibility (even limited because of the NCM as described in chapter 3.3.3) can be of great help for the HV and EHV voltage stabilisation compared with the “Orig” scenario.

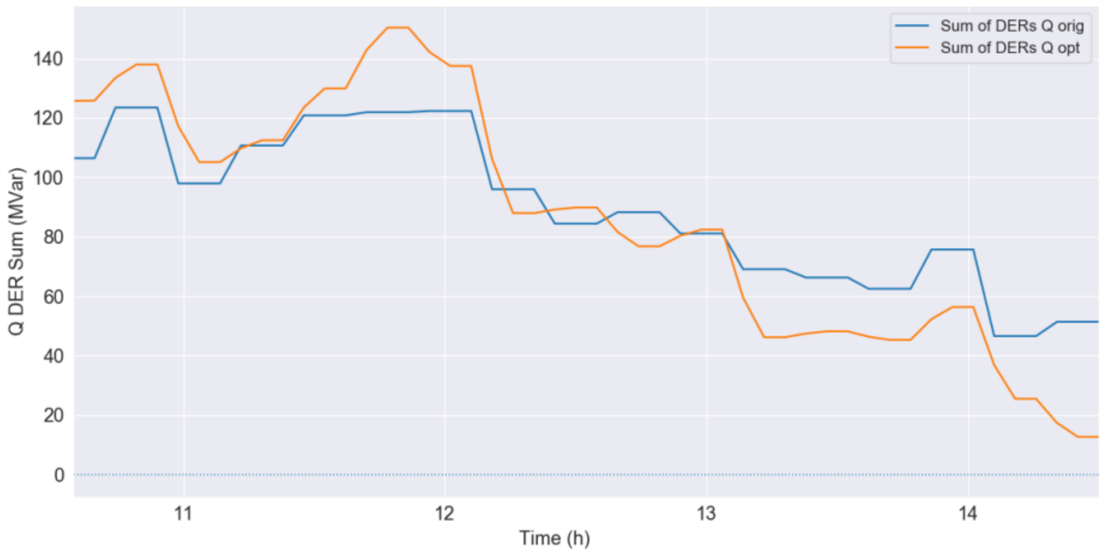


FIGURE 3.22 – SUM ALL Q OF ALL DERS IN SUBNET SAXONY-ANHALT WITH FLEXIBILITY OPTIMISATION BY DSO

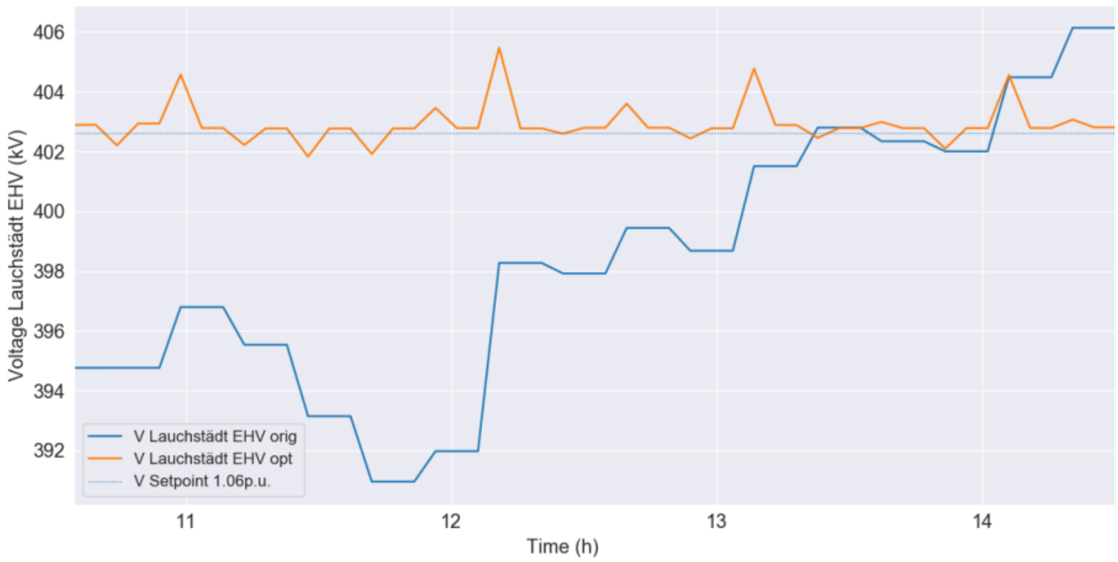


FIGURE 3.23 – EHV NODE VOLTAGE OF SUBSTATION LAUCHSTÄDT WITH FLEXIBILITY OPTIMISATION BY DSO

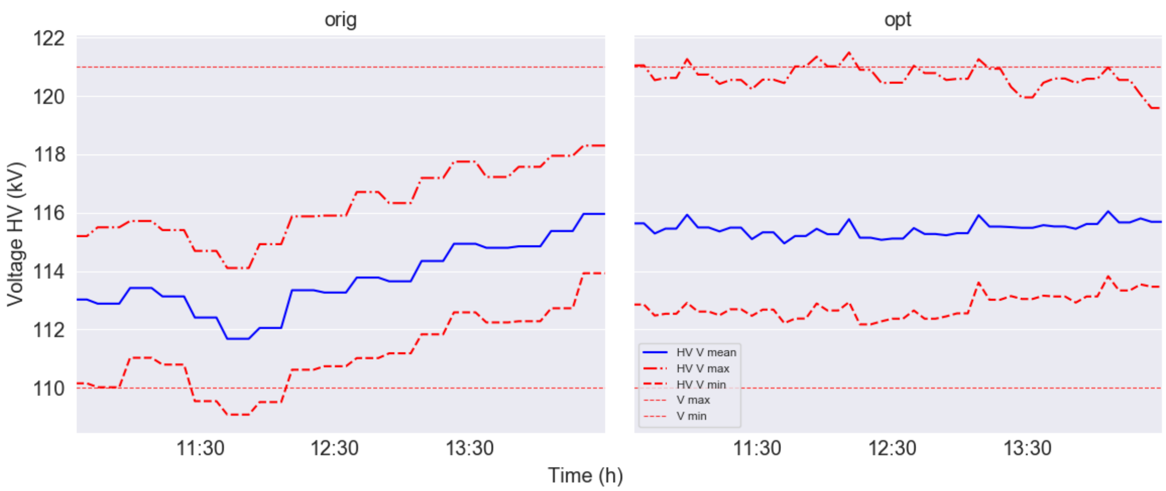


FIGURE 3.24 – VOLTAGE PROFILE OF HV GRIDS IN SUBNETS SAXONY-ANHALT WITH FLEXIBILITY OPTIMISITION BY DSO

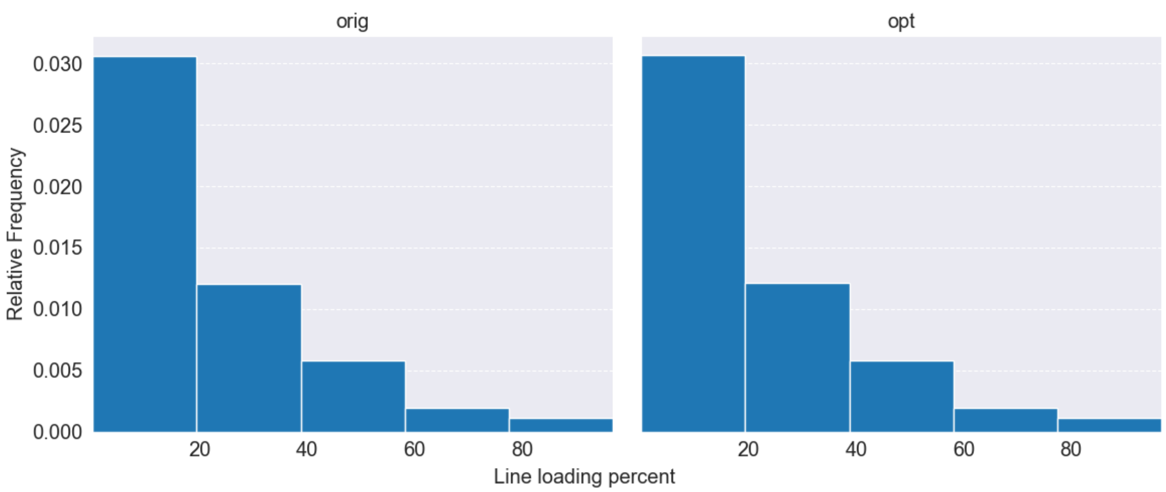


FIGURE 3.25 – LINE LOADING PERCENT IN HV GRID OF SUBNETS SAXONY-ANHALT WITH FLEXIBILITY OPTIMISATION BY DSO

SIMULATION WITH DECENTRALISED CONTROL

In this section, OFRS is performed with *TS Col* without the reactive power mode of remote Q set-points and the results will be presented. A second, modified, historical P time series of DERs is generated and simulated. In this time series, more DERs are involved in NCM with the total sum of curtailment remaining unchanged, but with none of them being curtailed below 20% of the installed capacity, so that full reactive power flexibility remains available. This time series is named as "new" in this section, since it is important to analyse whether with full reactive power flexibility from DERs the voltage collapse of HV and EHV grid could have been avoided e.g. with only decentralised control. The tap position of OLTCs is simulated according to the historical time series. The simulation scenarios covered in this chapter are listed in Table 3.6.

TABLE 3.6 – SIMULATION SCENARIO DESCRIPTION FOR TS COL WITHOUT DSO OPTIMISATION

Scenario name	P Time series	Q control mode (see Table 3.2)
Case 1_orig	Original	Cosphi
Case 2_orig	Original	Q0
Case 3A_orig	Original	QU (voltage set-point 1.05p.u.)
Case 3B_orig	Original	QU (voltage set-point 1.07p.u.).
Case 1_new	New	Cosphi
Case 2_new	New	Q0
Case 3A_new	New	QU (voltage set-point 1.05p.u.)
Case 3B_new	New	QU (voltage set-point 1.07p.u.).

Figure 3.26 shows the two types of the P time series and Figure 3.27 shows the sum of all P and all Q from all DERs.

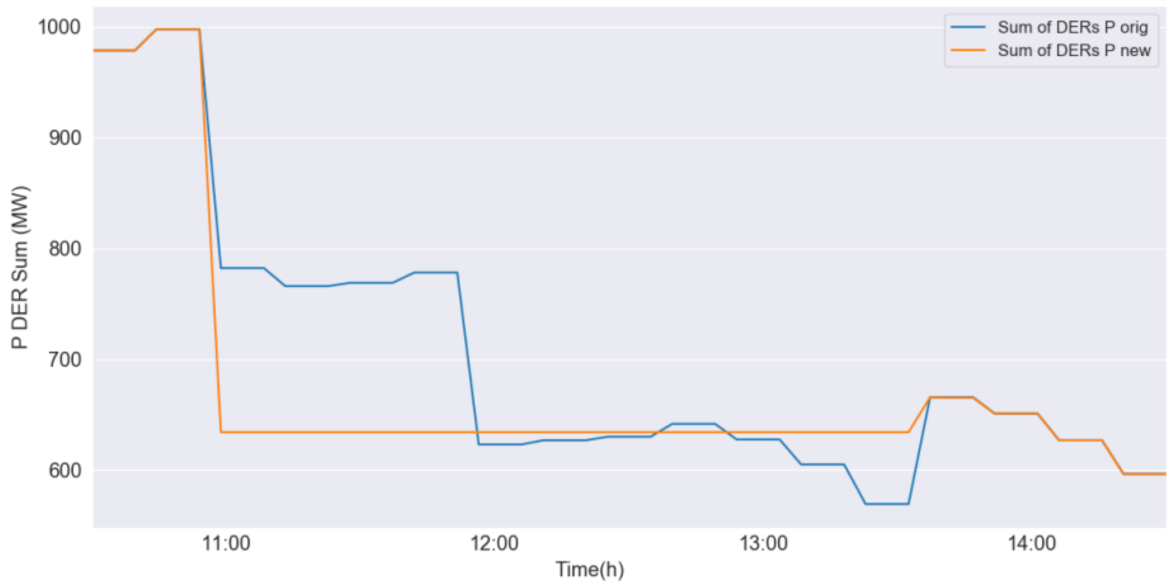


FIGURE 3.26 – TWO TYPES OF SUM OF ALL P OF ALL DERS IN SUBNET SAXONY-ANHALT

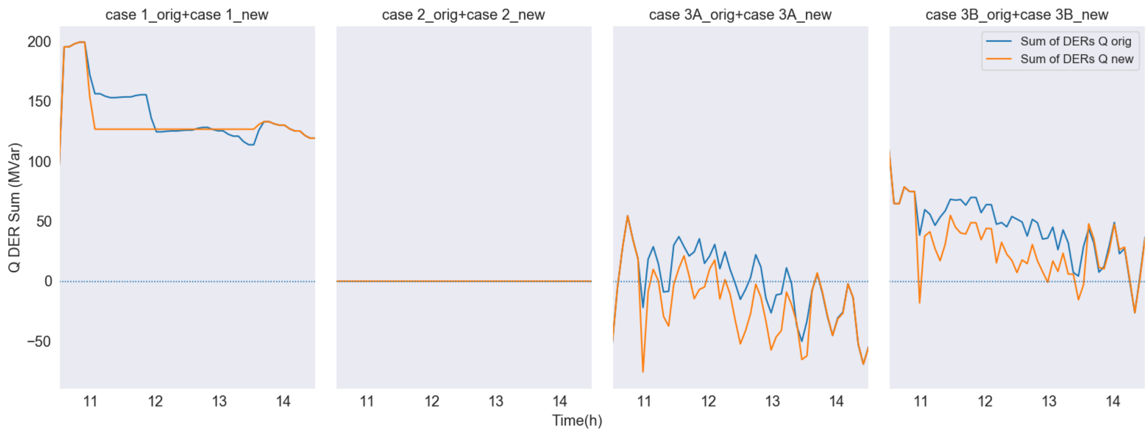


FIGURE 3.27 – SUM ALL Q OF ALL DERS IN SUBNET SAXONY-ANHALT UNDER DECENTRALISED CONTROL

It can be observed that in the "original" time series, the active power gets curtailed in two steps for the NCM ordered by 50Hertz, while in the "new" time series the two steps NCM are carried out in one step with all DERs get curtailed to a minimum 20% of the installed capacity. The resulting reactive power over time of all scenarios is shown in Figure 3.27. Similar to the observation made for the manually generated time series, in scenario "Case 3A_orig", "Case 3B_orig", "Case 3A_new" and "Case 3B_new", the reactive power oscillated numerous times. In "Case 3B_orig" and "Case 3B_new", with the higher local voltage set-point, the DERs tend to infeed more capacitive reactive power than in "Case 3A_orig" and "Case 3A_new". Figure 3.28 presents the voltage over time at the EHV substation Lauchstädt under decentralised control.

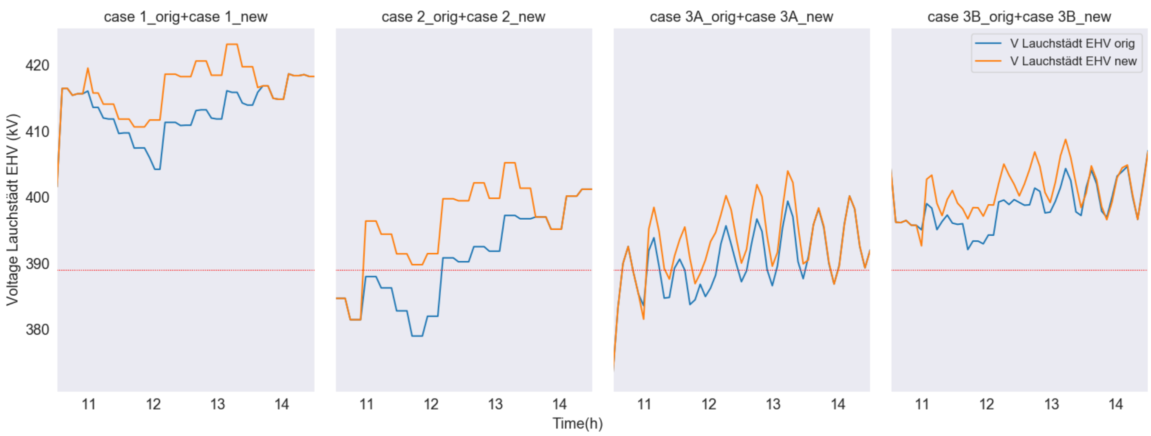


FIGURE 3.28 – EHV NODE VOLTAGE OF SUBSTATION LAUCHSTÄDT UNDER DECENTRALIZED CONTROL

In the cases with original active power time series with different Q modes, the voltage at substation Lauchstädt is very different between the cases, as shown in Figure 3.28. In "Case 2_orig" and "Case 2_new", the DERs are not in-feeding any capacitive reactive power and hence the voltage at Lauchstädt is even lower than in the original case. In "Case 1_orig" and "Case 1_new", if all DERs had provided infeed with maximum reactive power, the voltage collapse could have been avoided. However, from Figure 3.29 it can be told that voltage violated the lower limit multiple times in the HV grid in "Case 1_orig" and "Case 1_new". This behaviour indicates that enough reactive power flexibility is still available in the local grid, and as the result of these coordinated flexibility usage with the DSO optimisation shows, the voltage at EHV grid can be still stabilised. In "Case 3A_orig" and "Case

3A_new", the DERs try to stabilise local voltage at 1.05 p.u., which does not have enough effect to stabilise the voltage at GCP for the EHV grid. Under scenario "Case 3B_orig" and "Case 3B_new" with local voltage set-point 1.07 p.u., the voltage collapse at EHV grid is more solved as before with very less local voltage violation.

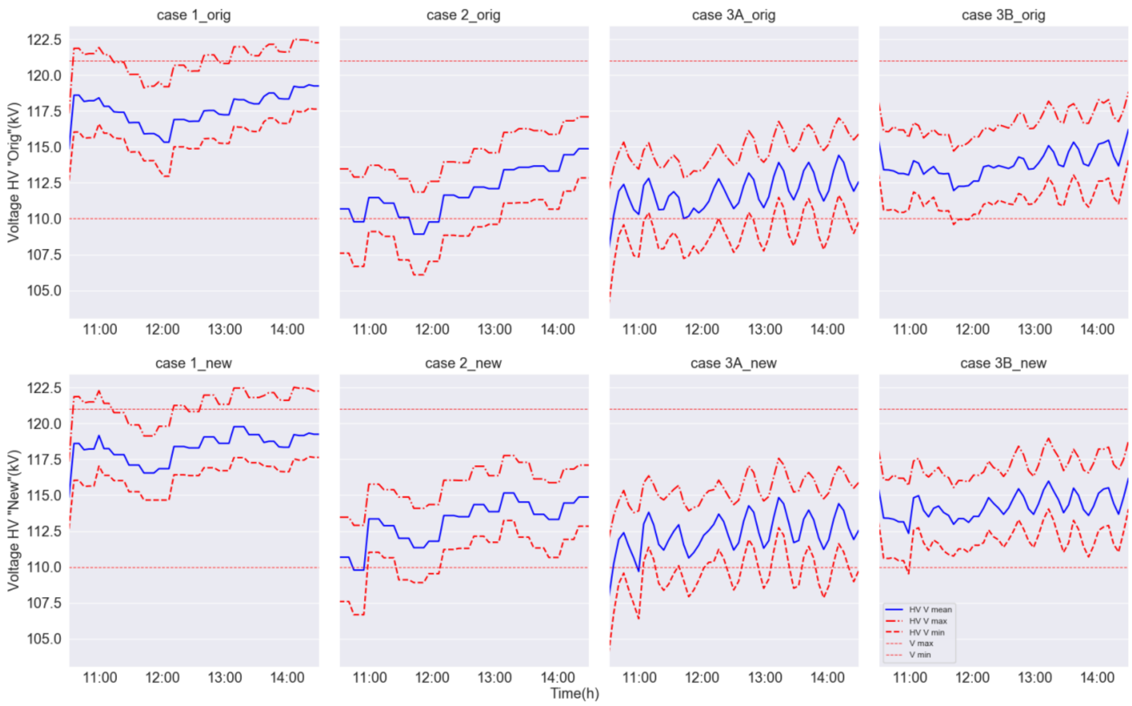


FIGURE 3.29 – VOLTAGE PROFILE OF HV GRIDS IN SUBNETS SAXONY-ANHALT UNDER DECENTRALIZED CONTROL

From Figure 3.30 it can be seen that, for all the scenarios, the line loadings of the HV lines are below the limits, and no line exceeds the allowed maximum line loading of 100% in the N-0 case.

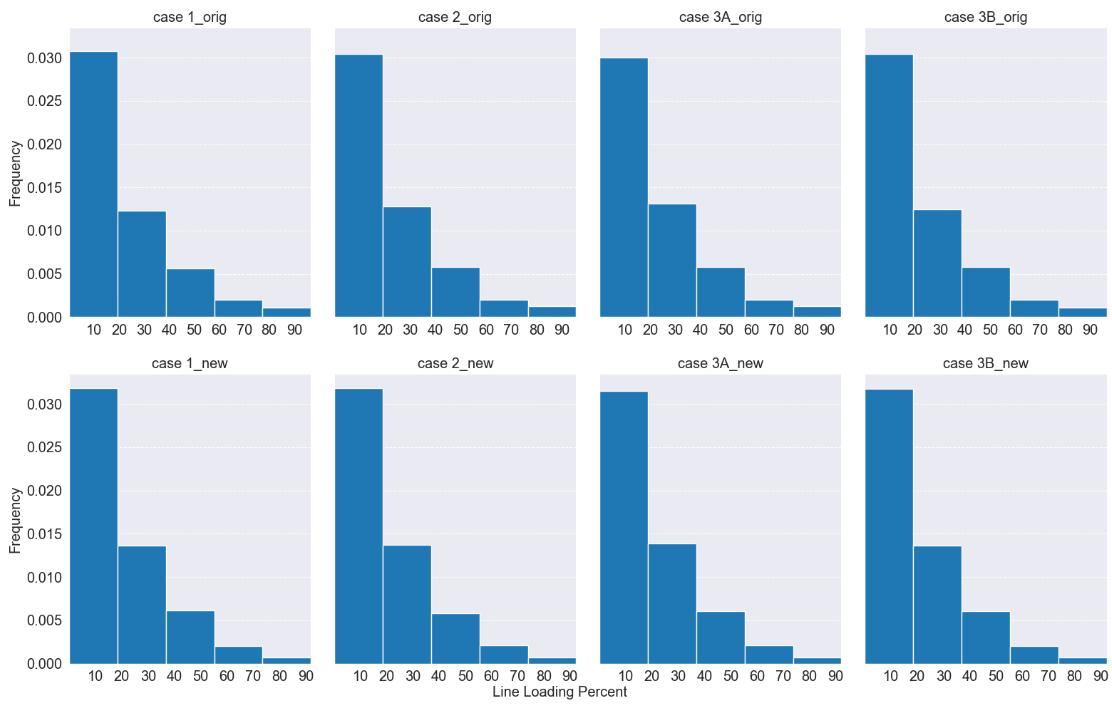


FIGURE 3.30 – LINE LOADING PERCENT IN HV GRID OF SUBNETS SAXONY-ANHALT

Reactive power in-feed from DERs helps to stabilise the voltage in the HV and EHV grid as indicated in Figure 3.28 and Figure 3.29 in multiple cases. Although some DERs were completely shut down, there would still have been enough theoretical Q flexibility from those DERs, which were not involved in the NCM, from the local grid to support the local and global voltage. However, decentralised control alone is, according to the simulative results, not enough for the utilisation of these reactive power flexibility for overall voltage stabilisation, because the voltage support from the DERs could potentially lead to local voltage problems. From all the test scenarios, only in the scenario "Case 3A_ori" and "Case 3A_new", DERs can help stabilising the global and local voltage with very little local voltage violation. This result shows the possibility of optimising the decentralised Q modes of DERs in the Mitnetz grid, with which the voltage of the local grid can be better stabilised.

Concluding, by comparing the two simulations with flexibility optimisation by DSO and with decentralised control, the advantage of a flexibility optimisation by DSO is obvious. The voltage of the local and EHV grid is much better stabilised even with only limited availability of reactive power flexibilities from DERs due to NCM.

3.4 PRELIMINARY CONCLUSIONS

In chapter 3 of this deliverable, the grid simulation tool of the German demonstration and its simulation results are presented. The basic functionality of the grid simulation tool, the accuracy of the asset modelling and the whole data processing process is verified with offline simulation, which shows the grid simulator to be suitable for standalone and online studies of the distribution grid with lots of DERs. Considering different modes of exploitation of flexibility from DERs, the impact on the grid is assessed with multiple scenarios with different DER modes, HV/MV automatic tap modes and with DSO optimisation in offline simulation.

In the offline simulation, firstly time series *TS Var* is used, in which the impact on the HV and MV voltage from different DER modes and HV/MV tap changer is assessed. The main conclusion here is that the HV/MV tap changer is essential to MV voltage stabilisation, but is less effective for voltage stabilisation in the HV grid.

A special case *TS Col*, which is a real-life example of how reactive power flexibility from the DERs in the HV grid could have helped avoiding voltage collapse in an extreme case, is assessed in offline simulation with different DER modes and DSO optimisation. In the simulation, with multiple decentralised reactive power modes tested, some strategies, e.g. QU1.07 for the *TS Col*, show the potential of using local reactive power flexibility for local and global voltage stabilisation. However, an overall satisfying allocation of decentralised DER modes can only be achieved with a thorough study. Furthermore, flexibility optimisation by DSO offers the best results in voltage stabilisation. But because of the process complexity, time delay of the real time optimisation cannot be avoided in the real operation. The influence of the delay will be further analysed and tested in the online simulation with demonstrator. The optimisation based on forecasting and its comparison to the real time optimisation will be tested in the same manner.

From the grid operation point of view, no major line loading violation is observed in local HV grid in the *TS Col* cases. However, the reactive power from DERs have decisive effects on the HV voltage stability. The system and methods developed in German demonstration show promising application in utilising local reactive power flexibility as a systematic way to sustain the local voltage stability.

Further results of the usage of flexibility of the HV grid for transmission grid from the optimisation by DSO are presented in deliverable D6.5 [1]. Deliverable D6.5 will evaluate the flexibility range and analyse the usage of active and reactive power flexibility considering assets availability and grid limitation in more detail. With the grid simulator presented in this deliverable, the result of co-simulation with demonstrator in mode ONRS will be presented in deliverable D6.7 for the German demonstration. The concept of the “digital twin” of the German demonstrator will be realised with the laboratory demonstrator. Innovative strategies for offering flexibility from distribution grid to the transmission grid can be verified during the real operation and special cases can be further analysed with the grid simulator in parallel.

Future tasks (out of the project scope) for the improvements of the grid simulation are to include the DERs from the MV grid in the grid modelling, so that more flexibility can be expected from the local grid. The transmission grid modelling can be extended or a grid equivalent to represent the transmission grid can be utilised, so that the simulation could be more reality-close with the extra information from the overall grid areas available. Furthermore, an interesting investigation point regarding the grid simulator itself, is to extend its functionality to enable further dynamic simulations, with which the frequency stabilisation and further dynamic topics can be evaluated.

4. NETWORK SIMULATION FOR THE ITALIAN DEMONSTRATOR

This chapter presents the simulation approach and the corresponding tool developed for the Italian demonstrator. As described in detail in Chapter 2, the innovation brought by this simulation approach consists in exploiting the functionalities of the SCADA network calculation module in off-line operations and apply them to different operating scenarios, which cannot be fully reproduced in the physical set-up. This leads to the opportunity to model new network scenarios, assessing the actual potential of DERs which can be aggregated at primary substation level. The result is a portrayal of network operations in presence of high levels of flexible RES, focused on supporting service provision to the TSO.

The purposes of simulation tests within the Italian demonstrator are here summarized:

- Analysis of the actual range of total active and reactive power capability of the demonstrator network, within the primary substation boundary;
- Evaluation of different network scenarios, in order to investigate the scalability of flexibility potential for increasing numbers of flexible resources;
- Evaluation of the impact of flexibilities exploitation, in different operating conditions, on network constraints;
- Assessment of the relevance of exploiting different type of flexibility resources, including network assets (such as STATCOMs and BESS) and dispatchable energy sources, of their availability and their reliability.

The preliminary simulation results presented at the end of this chapter provide a deeper knowledge of the network behaviour in specific operating conditions, giving valuable information to define coherent and sound test cases and to identify the suitable settings of the network assets to be applied in the field tests.

4.1 INTRODUCTION

The Italian demonstration is set on a portion of distribution network of *e-distribuzione*, heading to a single HV/MV primary substation, characterised by high PV penetration and low load consumption. Due to frequent back-feeding phenomenon, this network has been selected for testing smart grid solutions: the network control system integrates a new generation of Intelligent Electronic Devices (IEDs) - allowing the remote control of some flexible generators – and an advanced network calculation platform, which allows to run techno-economic optimisation procedures aimed to efficiently manage flexible resources. In addition to RES operated by private stakeholders, the Italian demonstration includes also some DSO-owned flexible resources: one 1MVA/1MWh Battery Energy Storage System (BESS) and two 1.2 MVAr Static Synchronous Compensators (STATCOMs) modules. The exploitation of these types of assets is of general interest so their potential in supporting the ancillary services provision from distributed resources will be investigated in detail, in order to give useful references for their application in other network scenarios.

The purpose of the Italian demonstration, within the EU-Sysflex project framework, is to analyse how the DSO (and/or a local Market Operator) can manage a full portfolio of flexibilities connected to its network in order to support ancillary service provision to the TSO network. This process was modelled in Task 3.3 of the EU-SysFlex project and is presented in deliverable D3.3 [1] through two Business Use Cases: the first one describes a business process focused on provision of active power flexibilities from distribution grid for mFRR/RR and congestion management services; the second one describes a business process focused on the management of the reactive power exchange at primary substation interface, for supporting voltage control and congestion management services. These goals must be necessarily achieved guaranteeing secure operations of the distribution grid; therefore, these business processes need, specifically, the support of functions for network techno-economical optimisation.

These functions were modelled in Task 6.2 and are presented in deliverable D6.1 [1] in two System Use Cases, which describe, respectively, the optimisation of the distribution network in presence of active power flexibility bids and their aggregation in a power/cost parametric curve, and the optimisation of the distribution network in presence of a reactive power constraint at primary substation. The optimisation routine developed for supporting these functions include also a network simulation functionality, which is described in the next sections. A schematic overview of the links between use cases, functionalities and tools is presented in Figure 4.1.

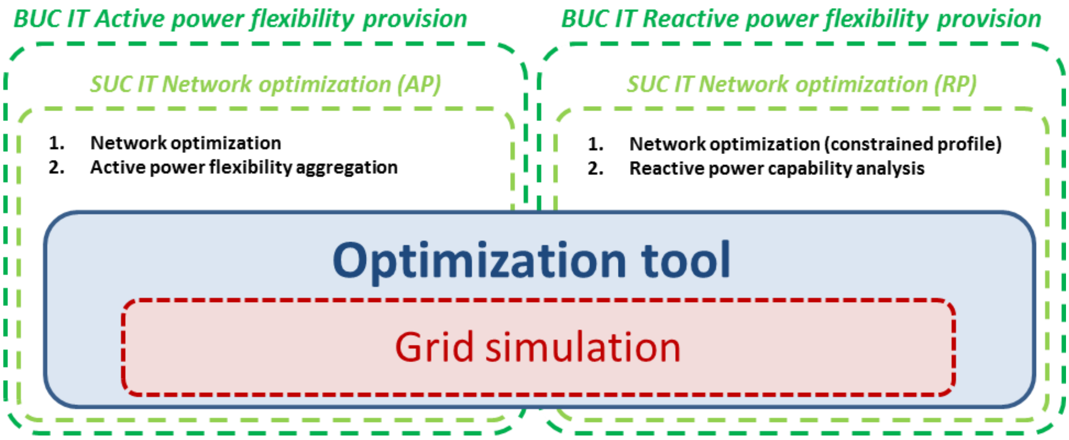


FIGURE 4.1 – USE CASES, FUNCTIONALITIES AND TOOLS RELATIONSHIPS SCHEME FOR ITALIAN DEMONSTRATOR

4.2 DESCRIPTION OF THE SIMULATION PROCESS

This section presents the complete description of the simulation process, detailing the main characteristics of the demonstration network, its data sets, the theoretical approach and the hypotheses behind the adopted simulations scenarios.

4.2.1 NETWORK DATA

The demonstration network feeds a predominantly rural area with a low density of residential loads and some relevant industries. It has a branched structure in order to reach the disperse loads and generators, and so the length of some branches is quite relevant; the overall lines length is about 320 km. The branched structure determines also a higher number of nodes (more than 600) compared to the networks that are usually found in literature. This increases the requested performances on speed on the algorithms used to operate the network.

The primary substation includes two OLTC equipped 25 MVA HV/MV transformers (132/15 kV); for the purposes of the project activities, two 1.2 MVAr STATCOM modules will be connected in cascade, one for each transformer.

Specific to this network is the presence of system operator-owned battery storage: it has a circular capability of 1 MVA range but, for simplified calculations, a square capability with a 1.42 MVA maximum range is considered.

The low urbanisation of the territory supported the installation of both small and medium scale PV plants. Additionally, some industries installed biomass generators (CHP: combined heat and power generators) for their own electricity/thermal needs (biomasses are quite cheap and readily available in that specific area). A medium-size hydro plant is installed on to the river which crosses the area, and it is connected close to the primary substation. Table 4.1 summarizes the maximum power output by type of generators, while Table 4.2 report the maximum output of the 4 controllable generators in demonstrator set-up; it should be noted that, usually, power plants generate only a fraction of their maximum power output.

TABLE 4.1 – MAXIMUM GENERATION POWER OUTPUT BY TYPE

Generation sources	Maximum Power [MW]
PV – MT	15
PV – BT	1
Other (mostly biomass)	7.5
Hydro	5.4

TABLE 4.2 – MAXIMUM POWER OUTPUT OF CONTROLLABLE GENERATORS IN ITALIAN DEMONSTRATOR

Controllable generators	Maximum Power [MW]
G8	1
G19	0.5
G20	0.5
G25	1

The demonstration network has a nominal voltage of 15 kV and it is normally operated with a fixed tap of 1.01 p.u.; this setting is selected based on practice, since it is the most suitable set-point for keeping the voltage within ±5% of the nominal value for almost all the operating conditions normally experienced in this network. By the way, OLTCs set point can be adapted, time by time, in order to cope with the actual operating conditions.

The most up-to-date available network data are considered for network modelling, in order to keep network model used for off-line tests as close as possible to the actual network, upon which on-line tests will be based. For load and generation profiles, two different types are considered, respectively, for LV users and MV users: LV users profiles come from normalised profiles, while MV user profiles come from real field measurements. LV users are clustered in different groups (residential, industrial, PVs…) and each corresponding profile is standardised on four seasons and three weekdays (workday, Saturday and Sunday) bases, resulting in 12 standardised profiles in total. For each user, the actual power profile is calculated by multiplying the nominal power value with the standardised profile. MV user profiles are based on historical data; in order to align them with LV profiles, the historical time-series of MV users are averaged on the same time-period bases of LV users (four seasons and three weekdays). Exploiting standardised profiles instead of real measurements based profiles may limit the occurrence of time-limited critical conditions during simulations, or may make them less observable; despite this limitation, standardised profiles are a suitable solution for modelling the average behaviour of the network and for simulating the real network operating conditions with reasonable accuracy.

Despite its size, if operated as described above, this network does not present relevant violations, since LV load is low, while largest MV loads and generators are connected close to the primary substation. Limited over-voltages may be observed in some nodes during the peak production of PV plants: they appear only in few nodes (very small percentage of the total), and they are limited in time and magnitude, usually the system operator keeps baseline set-points, otherwise suitable correcting actions are taken and the set-points changed accordingly.

The complete schematic of the demonstration network is presented in Figure 4.2.

FIGURE 4.2 – SCHEMATIC PICTURE OF THE ITALIAN DEMONSTRATOR NETWORK

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 773505.

4.2.2 ALGORITHMS AND MODELING

Simulations are carried out with the optimisation tool described in detail in deliverable D6.5 [1] , and in previous works [9]. Some adaptations are introduced in order to reach this goal, specifically the same solver was used but in a dedicated simulation environment and not within the SCADA system; this is essential to simulate the network in different operating conditions, since within the SCADA it is difficult to change the scenario settings (e.g. number of generators…) and the profile of generators and loads. Specific functions are developed in order to translate the data normally coming from SCADA (e.g. network characteristics, profiles…) in the correct input format for the optimisation algorithm.

Three simulation sets are performed changing the formulation of the optimisation problem in order to cover all the relevant use cases, briefly summarised in the following:

A. The goal of the first set of simulation is to evaluate the network behaviour in normal operating conditions, i.e. to determine active and reactive power exchanges in primary substation, voltages and currents and corresponding potential constraints violation for the normalised time periods and days (see 4.2.1 for reference). For carrying out this task it is necessary to adapt the optimisation problem in order to force the OPF to behave like a simple power flow (PF). This is achieved by introducing some modifications to the input of the optimisation algorithm: all the generators are set non-controllable, so their active and reactive powers are kept fixed to the initial values; the tap voltage is kept fixed at 1.01 p.u., so the OLTC cannot be used by the OPF as a lever for reaching an optimal solution. In such conditions, the OPF is unable to satisfy network constraints and so they are relaxed allowing the optimisation problem to converge and calculate a solution. This approach is equivalent to run a power flow imposing the slack node (as voltage reference) in the secondary bus-bar of the primary substation. Same simulations are repeated with controllable tap voltage and setting aiming at minimisation of network losses; a discrete OLTC model (step of 0.19 kV and dead band of 0.11 kV) was also considered (Figure 4.3):

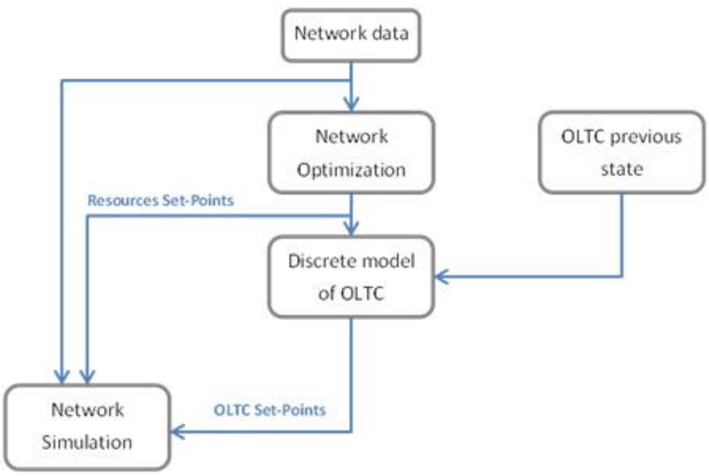


FIGURE 4.3 – SCHEMATIC WORKFLOW OF THE “DISCRETISATION” OF OLTC SET-POINTS

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 773505.

B. For the second set of simulations the goal is to determine the overall reactive power capability that can be provided by the aggregation of distributed resources at primary substation node. The adopted procedure [10] is based on the following assumptions: the generators are left free to exchange reactive power based on their capability; the exchange of reactive power at the primary substation is maximised by setting a high value of reactive power (absorbed or injected); the cost for the reactive power provided by distributed generators is set much lower than the cost for the reactive power provided by the slack generator (which ideally represent the power flow from the transmission network). In this way the OPF solver (see D6.5 [1] for a detailed explanation) is forced to use first all the resources available in distribution network to meet the power constraint at primary substation, returning the maximum exchange of reactive power that the distribution network could actually support. This procedure is followed for determining both the maximum injection and the maximum absorption of reactive power towards the transmission network.
Voltage and current constraints are neglected in order to determine, by the means of dedicated post processing analysis, how many constraints violations arise in these operating conditions.

C. Provision of active power modulation from distributed resources is evaluated: specifically, cumulative parametric curve (energy/cost) build up with active power flexibilities from local resources is calculated through the iterative process described in the following:

1. Evaluation of the active power exchange in primary substation, in the baseline scenario;
2. Selection of active power values, based on the total available power modulation and the requested precision of the parametric curve. This set of values represents the power variation in respect to the baseline;
3. Cyclically, the active power set-point of the slack node is fixed equal to the sum of the baseline active power value and one of the values from the active power variation set (from the first onwards); then the OPF is executed, in order to determine the resources which can support the active power exchange set-point, at minimum cost; based on the resources activated and their costs, the total and marginal costs for each step of the parametric curve can be calculated;
4. The process is repeated until no more resources can be activated (e.g. all the resources are used or the constraints block further activations).

The calculation process described above is applied both to upward and downward power regulation and for all the desired time intervals. In this way it is possible to compute the parametric bidding curve for different operating conditions. Furthermore, applying this process without considering the network constraints allows to determine the maximum range for active power exchange; on the other side, this process allows to identify where constraints violations arise and then, which are the portions of the network limiting the exchange of active power.

4.2.3 DESCRIPTION OF THE SIMULATION SCENARIOS

For the purposes of the simulations presented in this document, five different scenario cases are selected. Basically, their scope is to highlight the increase in flexibility range versus the number and type of controllable resources exploited, and the different contribution they can provide to both the reactive power capability and active power parametric curves, based on their technical characteristics.

Case 1 considers only the four available PV generators in the set-up; this can be considered as a base scenario since it includes a very low number of controllable resources of the same type. Case 2 adds the battery storage (BESS), showing the expansion of the flexibility curves outside daylight time interval. Case 3 (see Figure 4.4) considers the actual demonstrator set-up (4PVs+BESS+STATCOMs) for the field tests to be performed in the next steps of the WP6. Finally, case 4 and case 5 (see Figure 4.5) deal with the increase of the controllable resources, in line with the future trends; since there are several PV plants connected in the demonstrator network, a specific case scenario for analysing only their impact is selected (case 4). The main features of these case scenarios are summarised in Table 4.3:

TABLE 4.3 – FLEXIBLE RESOURCES SET-UPS FOR THE SIMULATED CASES

	Case 1	Case 2	Case 3	Case 4	Case 5
Resources	4 PV generators (G8, G19, G20, G25)	Case 1 + BESS	Case 2 + STATCOMs	All PV gens + BESS + STATCOMs	All gens + BESS + STATCOMs

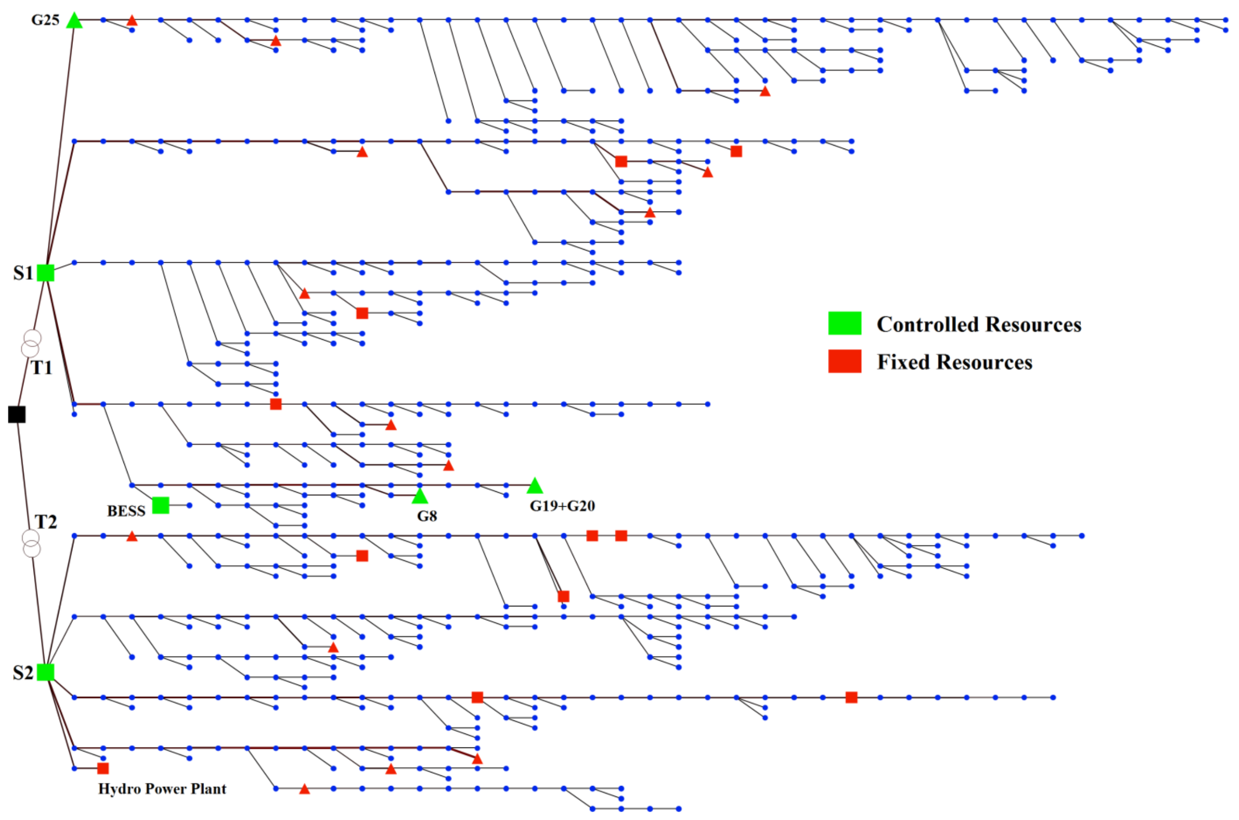


FIGURE 4.4 – SCHEMATIC PICTURE OF THE ITALIAN DEMONSTRATOR NETWORK: CASE 3 SCENARIO

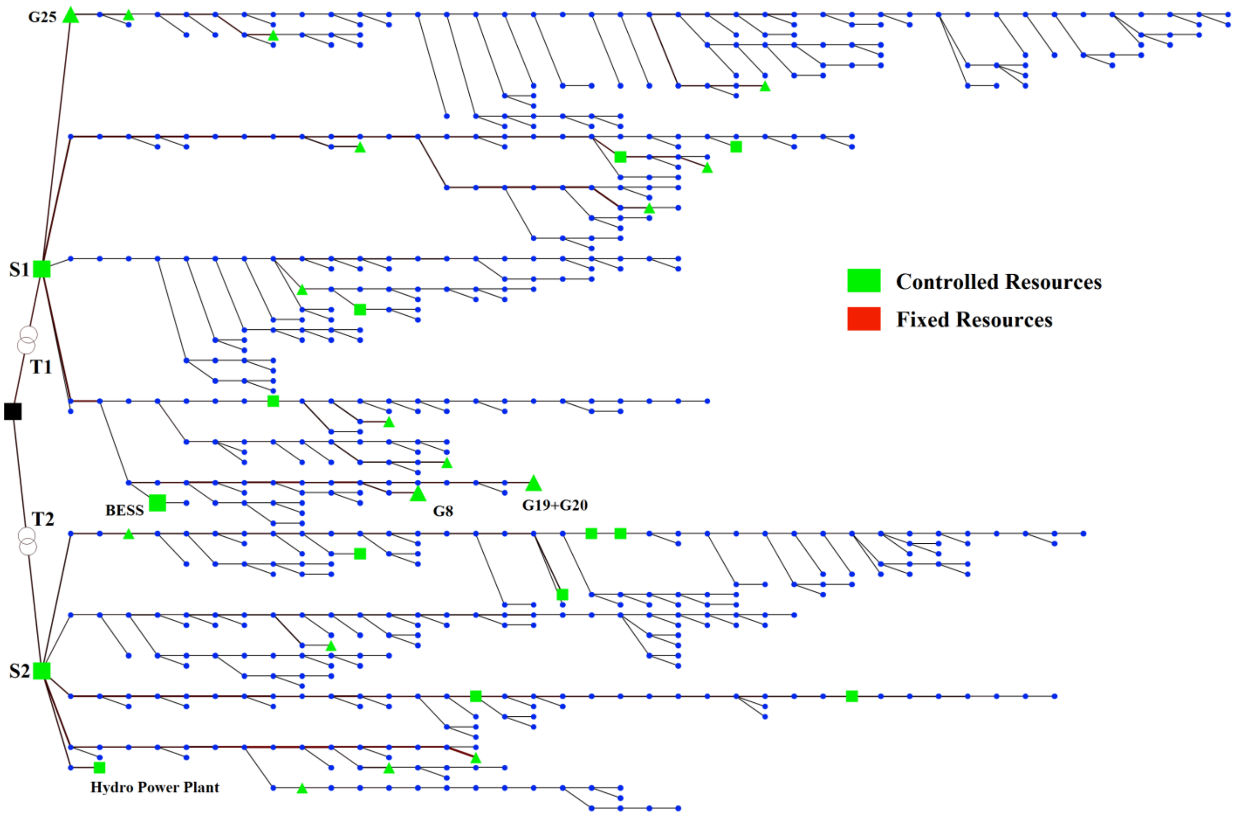


FIGURE 4.5 – SCHEMATIC PICTURE OF THE ITALIAN DEMONSTRATOR NETWORK: CASE 5 SCENARIO

4.3 SIMULATION RESULTS

In this section, the results coming from the carried out simulations are presented and discussed; for each of the three simulation sets presented in Section 0, the five test case scenarios presented in Section 4.2.3 are simulated. Furthermore, the OLTC behaviour in the normal operations of the network is analysed. These results show the actual range of power capability of the demonstrator network, the scalability of flexibility potential for increasing numbers of flexible resources as well as the relevance of exploiting different type of resources, and the impact of flexibilities exploitation on network constraints.

4.3.1 BASELINE SCENARIO WITH FIXED OLTC TAP VOLTAGE

The baseline scenario is identified by the normal operations of the demonstrator network, i.e. considering fixed normalized load/generator profiles and fixed tap voltage of 1.01 p.u. of the nominal voltage (15.15 kV), as presented in section 4.2.1. The resulting active and reactive power exchange profiles at primary substation for the four quarters of an average year are shown, respectively, in Figure 4.6, Figure 4.7, Figure 4.8, Figure 4.9: positive figures represent power absorption from the 110kV transmission network via primary substation, while negative figures represent power injections to the transmission network (back-feeding), via primary substation.

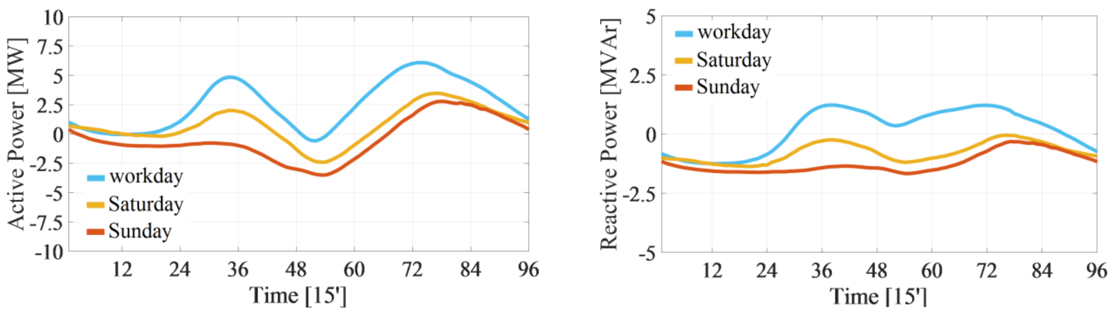


FIGURE 4.6 – A) ACTIVE POWER EXCHANGE AND B) REACTIVE POWER EXCHANGE IN PS IN FIRST QUARTER OF YEAR (JAN-MAR)

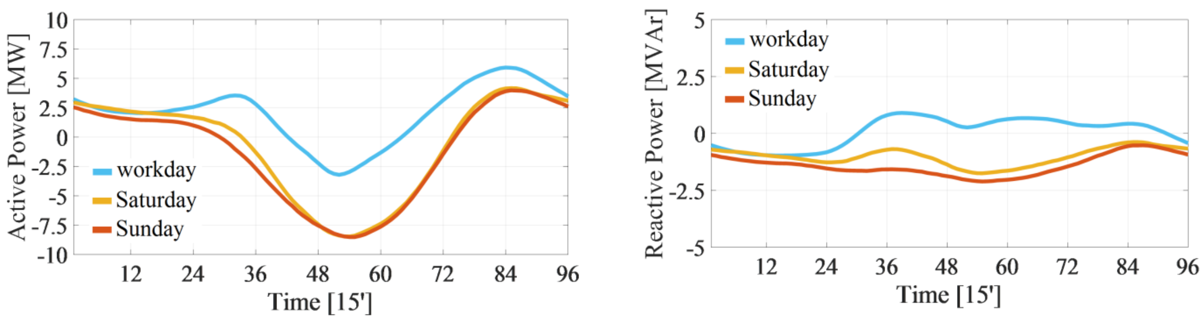


FIGURE 4.7 – A) ACTIVE POWER EXCHANGE AND B) REACTIVE POWER EXCHANGE IN PS IN SECOND QUARTER OF YEAR (APR-JUN)

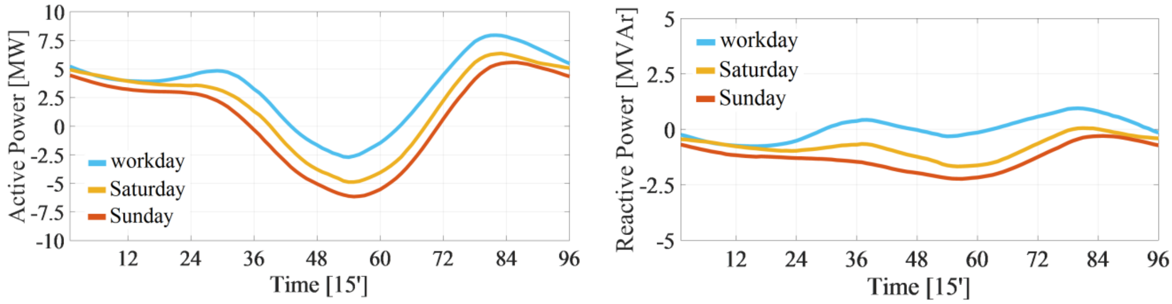


FIGURE 4.8 – A) ACTIVE POWER EXCHANGE AND B) REACTIVE POWER EXCHANGE IN PS IN THIRD QUARTER OF YEAR (JUL-SEP)

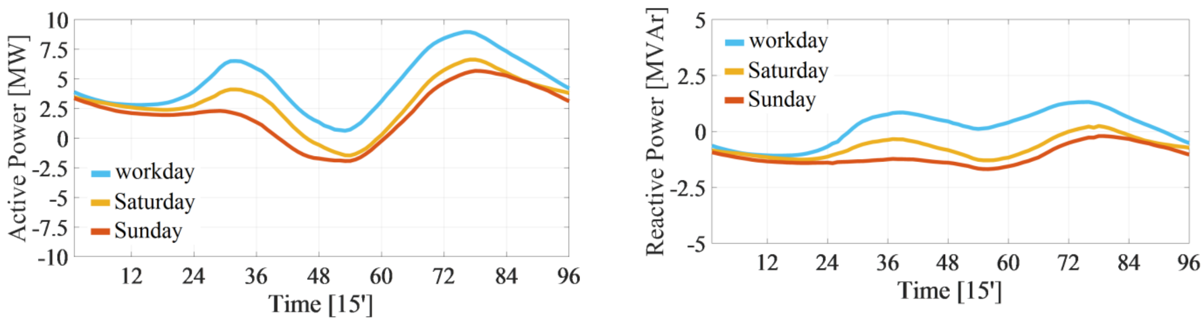


FIGURE 4.9 – A) ACTIVE POWER EXCHANGE AND B) REACTIVE POWER EXCHANGE IN PS IN FOURTH QUARTER OF YEAR (OCT-DEC)

The active power profile follows the typical shape of a network with a high penetration of photovoltaic generators. The maximum reverse power flow is reached on Sunday of the second quarter and is more than 8 MW. The reverse power flow is lowest in the workday due to the contribution of industrial and commercial load. The second quarter has the highest reverse power flow because the load is low on Sunday afternoon (the air conditioning is not already started) and there is still a contribution from the hydro generators. Particularly, the contribution of the hydro and some biomass generators is high enough to determine reverse power flow also in the night of the first quarter. The contribution in the second quarter is reduced, but still present. The maximum absorption of power is reached in the evening of the workday of the fourth quarter and it is about 9 MW. The maximum difference between the evening absorption and the day-time reverse power flow is again reached in the Sunday of the second quarter and is equal to about 12.5 MW, but other days experience similar values.

The reactive power flow absorption is quite limited with a peak of about 1.5 MVAr in the fourth quarter, when the load is maximum. This power can be compensated by a capacitor bank of about 1.8 MVAr installed in the primary substation that will be substituted in the project by the STATCOMs. During night-time and in the Saturdays and Sundays there is a reverse power flow of reactive power, due to the high capacitance of the lines of the networks, which compensate the reactive power absorption of loads. The mean reverse power flow of reactive power is about 2 MVAr. The reactive power flow highly depends on the power factor of loads. In accordance to the new rules for reactive power absorption of loads, the power factor of secondary substation is taken equal to 0.95, while the reactive profile of MV users comes from real profile. Lower power factors in secondary substations could determine higher reactive power absorptions than those reported here.

The main reason behind the fixed tap voltage of 1.01 p.u. is to avoid under-voltages, in each node of the network, in the highest load conditions (as requested by the network operator). While this set-point, as explained in 4.2.1, is the best compromise for keeping node voltages within the limits (0.95 to 1.05 p.u.), over-voltages may arise in some nodes (more likely the generation nodes and the closer ones) during the maximum PV plants production, i.e. during the hottest season.

Figure 4.10 shows the yearly lowest voltage profiles (A) and the highest voltage profiles (B) in baseline operating conditions which occur, respectively, during the workday of the fourth quarter (cold season, high consumption, low PV generation) and during the Sunday of the second quarter (hot season, low consumption, high PV generation). In this second case, the highest node voltage exceeds the upper voltage limit by not more than 1% (1.059 p.u.) for slightly less than 5 hours. Since such conditions apply to less than 3% of nodes, they may not be considered critical by the system operator and if so no corrective actions are taken. Anyway, in different operating conditions (i.e. with higher production values, with lower consumption values or in presence of reactive power injection from the resources versus the primary substation) these same nodes are likely to experience higher or sustained over-voltages and so corrective actions must be taken. Further investigation about this topic is presented in section 4.3.3.

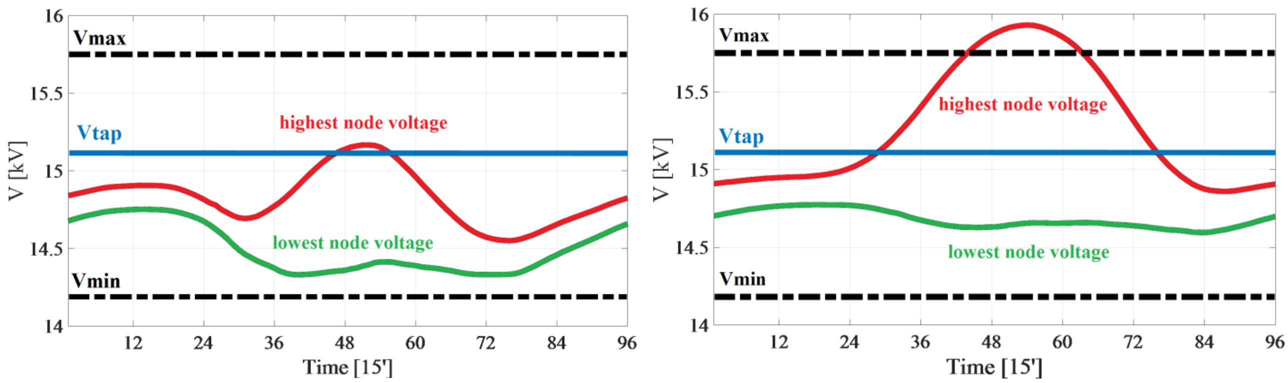


FIGURE 4.10 – A) LOWEST VOLTAGE PROFILES AND B) HIGHEST VOLTAGE PROFILES IN THE DEMONSTRATOR NETWORK.

In order to assess the behaviour of the network in normal operating conditions, node voltage values and line loading distribution are calculated and plotted, respectively, in Figure 4.11, Figure 4.12 and in Figure 4.13.

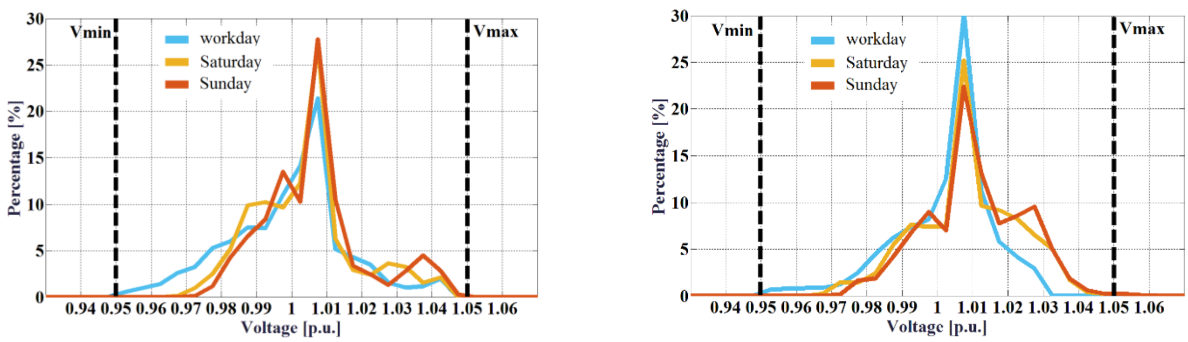
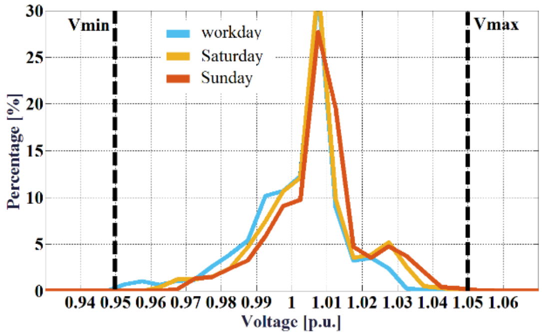


FIGURE 4.11 – PERCENTAGE DISTRIBUTION OF VOLTAGE MAGNITUDE IN THE A) FIRST QUARTER (JAN-MAR) AND IN THE B) SECOND QUARTER (APR-JUN).



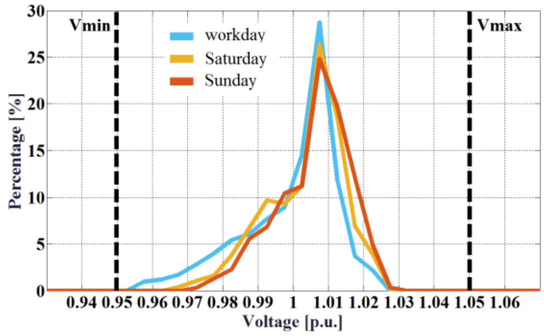


FIGURE 4.12 – PERCENTAGE DISTRIBUTION OF VOLTAGE MAGNITUDE IN THE A) THIRD QUARTER (JUL-SEP) AND IN THE B) FOURTH QUARTER (OCT-DEC).

From Figure 4.11 and Figure 4.12 it can easily be noticed that most of the nodes have voltage values very close to the transformer set-point of 1.01 p.u. and almost all of them are within the allowed limits. It is barely noticeable that few values stay around of upper limit, particularly in the central part of the year (March to September): these are the values assumed by the nodes which experience limited over-voltages during the maximum PV production, as discussed before. Here it is clearly visible that their impact on the network is negligible, and understand why they are often tolerated in normal operations.

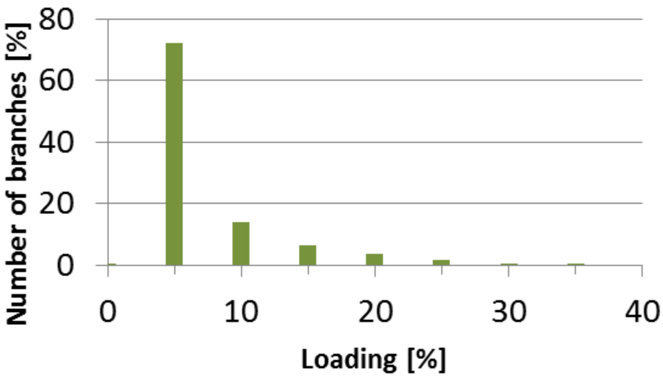


FIGURE 4.13 – LINE LOADING DISTRIBUTION IN BRANCHES, SUNDAY, SECOND QUARTER (APR-JUN), BASELINE SCENARIO

Figure 4.13 reports the line loading distribution in branches for the “worst” loading day (Sunday of the second quarter): it shows that line congestion in normal operations is not an issue, since most of the branches have an average line loading of 5% and the highest loading is far below the 50% of the branches capacity.

The results presented in this section depict the average state of the demonstrator network in normal operations, showing the active and reactive power profiles at primary substation node, as well as voltage and line loading distributions. This information is relevant for the next simulations since it represents the reference operating conditions for the capability analysis; it allows also to identify the potentially “weak points” of the network if it is operated outside of the baseline scenario.

4.3.2 BASELINE SCENARIO WITH CONTROLLABLE OLTC TAP VOLTAGE

A next step in assessing the baseline scenario is the simulation of OLTC operations. This process relies on the optimisation function, the objective of which is the minimisation of losses (a detailed description of the optimisation tool is presented in D6.5 [1]. Adaptations to the optimisation problem are introduced in order to use only the OLTCs as controlled asset and thus not to perform a full-scale network optimisation. Then, the discretisation of tap voltage regulation is also introduced, based on the process described in section 0. Figure 4.14 and Figure 4.15 report, as an example, the continuous and discretised tap voltage profiles for the third quarter, respectively for OLTC1 and OLTC2.

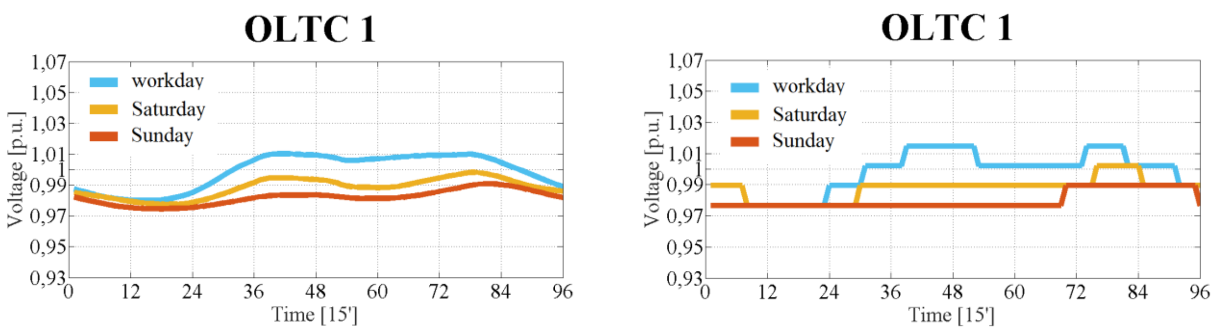


FIGURE 4.14 – TRAFO 1 TAP VOLTAGE PROFILES, THIRD QUARTER (JUL-SEP): A) CONTINUOUS AND B) DISCRETE

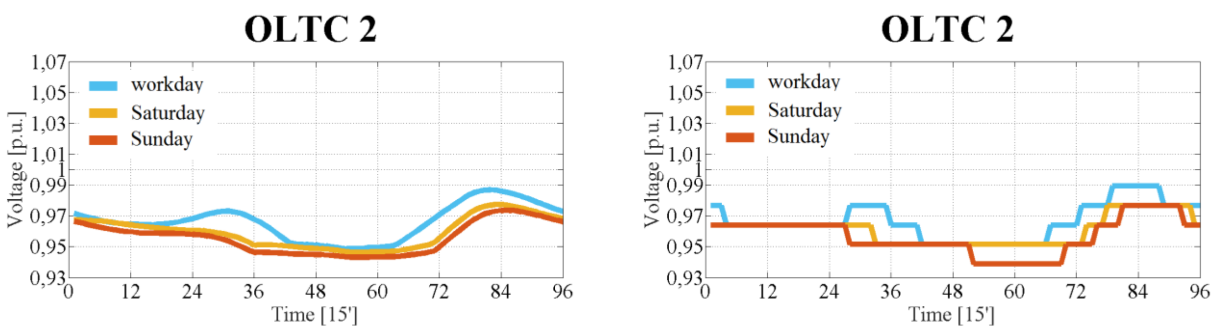


FIGURE 4.15 – TRAFO 2 TAP VOLTAGE PROFILES, THIRD QUARTER (JUL-SEP): A) CONTINUOUS AND B) DISCRETE

The comparison of these figures allows to clearly notice that the portion of the network managed by OLTC2 (the one connected to transformer T2, see Figure 4.2 for reference) is more affected by back-feeding phenomenon, represented by the drop of tap voltage values in the central part of the day; indeed, most of the large generators are connected to this part of the network. Another interesting aspect to be noticed is the “flattening” of the continuous profile during the central part of the day, clearly visible in Figure 4.15 A; this shows that tap voltage downward regulation cannot be pushed down further, in order to not violate the network voltage lower constraint. This condition does not represent an issue, since the convergence of the optimisation problem is achieved anyway, until the discretisation of tap voltage is applied; indeed, the Sunday tap voltage profile shown in Figure 4.15 B assumes values below the network voltage lower limit (0.95 p.u.), as they are the best discrete approximation of the continuous profile. In such cases it may happen that voltage level of some network nodes fall below the allowed limit, even after a successful optimisation. Furthermore, it can be seen that the discretisation of the tap voltage profiles requires a certain number of tap shifting: in baseline operating conditions they never exceed the reliability limit of 10-12 shifting per day imposed by the network operator (*e-distribuzione*), but it is evident that for operating conditions affected by a higher variability of network voltage, tap shifting constraints should be considered. Figure 4.16, Figure 4.17, Figure 4.18 and Figure 4.19 reports the node voltage values distributions, for all the quarters of year and for both the continuous and discrete regulation.

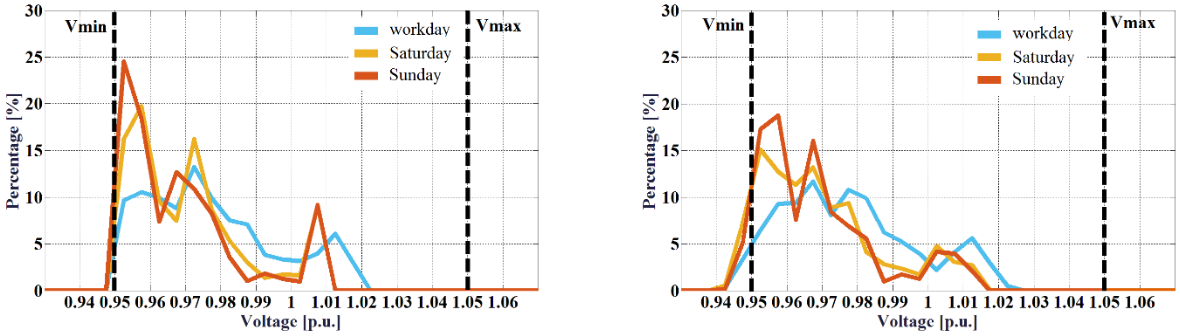


FIGURE 4.16 – VOLTAGE DISTRIBUTION, FIRST QUARTER (JAN-MAR): A) OLTC CONTINUOUS MODEL AND B) OLTC DISCRETE MODEL

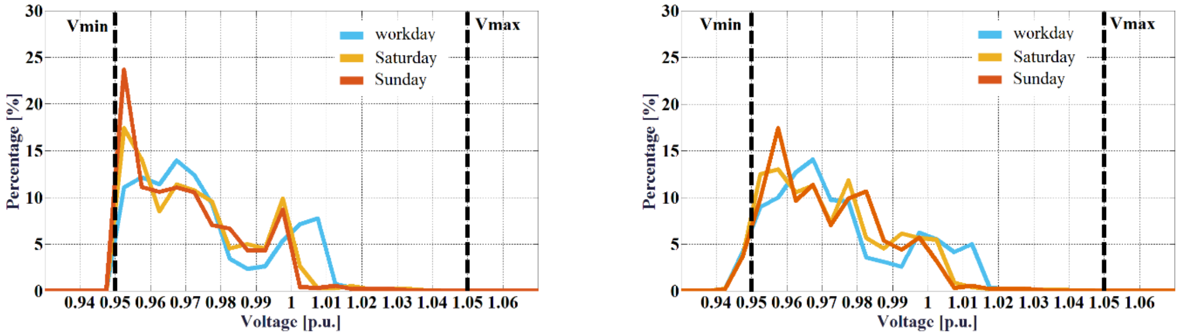


FIGURE 4.17 – VOLTAGE DISTRIBUTION, SECOND QUARTER (APR-JUN): A) OLTC CONTINUOUS MODEL AND B) OLTC DISCRETE MODEL

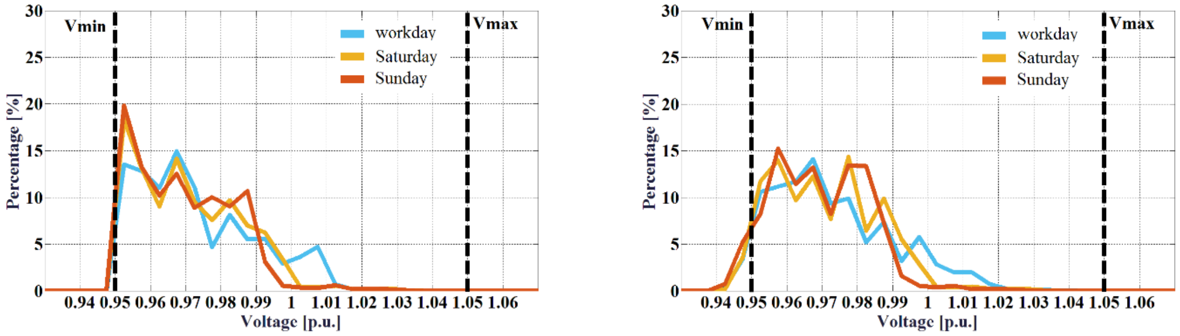


FIGURE 4.18 – VOLTAGE DISTRIBUTION, THIRD QUARTER (JUL-SEP): A) OLTC CONTINUOUS MODEL AND B) OLTC DISCRETE MODEL

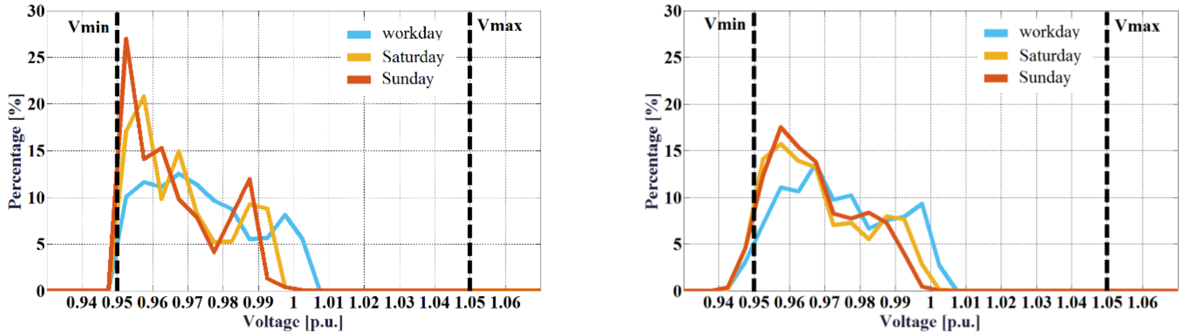


FIGURE 4.19 – VOLTAGE DISTRIBUTION, FOURTH QUARTER (OCT-DEC): A) OLTC CONTINUOUS MODEL AND B) OLTC DISCRETE MODEL

In these figures a mean voltage decreasing with respect to the previous case (fixed OLTC tap) can be noticed; this is the result of the loss reduction achieved by the optimisation routine, together with the Z modelling adopted for the loads. Discretisation of the tap voltage profiles lead to a more even spread of voltage values between nodes, resulting in a "flatter" distribution of voltage values compared to continuous tap regulation case: smaller voltage difference between nodes contribute also to reduce network losses. The occurrence of under-voltages in some nodes due to discretisation, discussed in the previous paragraphs, is clearly noticeable here: at least 5% of the nodes, through the whole year period, experience voltage values down to 0.94 p.u. (1% less than the minimum limit allowed, i.e. 0.95 p.u.). Contrary to the limited over-voltage occurrence during higher PV production, under-voltages are not tolerated, above all for long periods of time. For solving this issue, usually the minimum voltage set-point for tap regulation is increased by 0.5/1% (0.955/0.96 p.u.), practically resulting in a slight reduction of the OLTCs regulation band.

The results presented in this section show that the OLTCs exploitation could be useful for a better network management but, on the other side, it also entails some additional constraints which must be taken into account, specifically outside baseline operating conditions. These aspects are analysed more in details in deliverable D6.5 [1].

4.3.3 ANALYSIS OF THE AGGREGATED REACTIVE POWER CAPABILITY

The objective of the second set of simulations is to analyse and quantify the maximum range of reactive power flexibility the demonstrator network can provide and how it is impacted by network constraints.

The corresponding tests are carried out for all the five case scenarios presented in 4.2.3, and so for an increasing number of flexible resources.

Firstly, in order to estimate the maximum theoretical aggregated reactive power capability, the optimisation routines are disabled during tests, resulting in no corrective actions in presence of violations. In a second time, suitable adaptations are applied to the optimisation routine in order to quantify the violations which arise exploiting the full theoretical capability, and to determine how it should be reduced for avoiding such violations. In all the simulations a fixed OLTC tap voltage is considered, with a set-point of 1.01 p.u., in order to facilitate the comparison with the baseline scenario.

The maximum reactive power injection and absorption profiles at primary substation are simulated without network constraints; from these profiles, the mean maximum regulation band are calculated for the different cases and the corresponding values are presented in Table 4.4.

TABLE 4.4 – REGULATION BAND FIGURES FOR THE SIMULATED CASES

	Case 1	Case 2	Case 3	Case 4	Case 5
Regulation band [MVAr]	2.0	3.4	8.2	15.4	28.0

It should be noted that, in Case 3, the theoretical capability range is comparable with the mean active power exchange in the baseline scenario, i.e. 9MW (see Section 4.3.1). Again, in Case 5, the capability range is more than three times higher than Case 3.

Figure 4.20 presents the reactive capability areas versus the set-ups of the different case scenarios, and it shows very clearly how each type of resource impact on the aggregated capability.

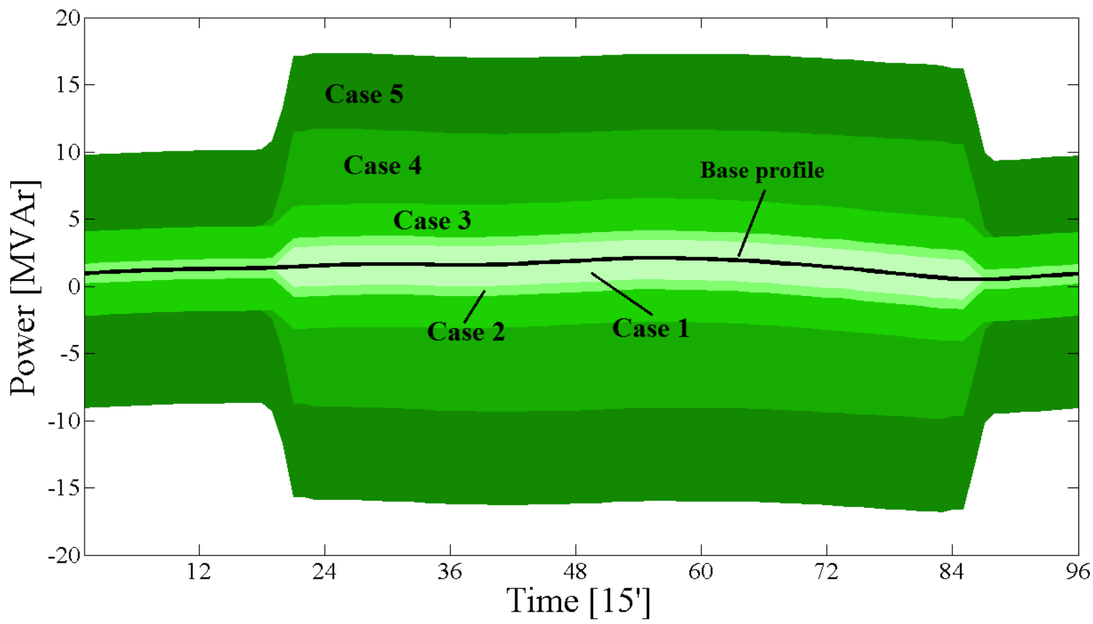


FIGURE 4.20 – PICTORIAL COMPARISON OF REACTIVE POWER CAPABILITY AREAS FOR THE CONSIDERED CASE SCENARIOS

Firstly, it is very noticeable that there is a huge boost to capability area given by the exploitation of all the resources and generators connected to the network and also of the PV plants themselves (Case 5 and 4, respectively); a full range of 20-30 MVAr modulation could be potentially achieved in the central hours of sunny days.

Both STATCOMs and battery storage complement the lack of reactive power flexibility in the night/evening hours, when the PV plants are not producing energy, even if with a sensibly different impact: the battery storage contribution is a fraction of that from the STATCOMs and it is quite small compared to all the other types of resources. In the night hours also the contribution to the capability area from the dispatchable generators (conventional, biomass and hydro plants), becomes evident, as they can provide more than twice the reactive power flexibility provided by the STATCOMs and battery storage.

The capability curves and the corresponding regulation band obtained from the simulations show the theoretical potential of the demonstrator network to provide reactive power flexibility; however, this potential may not be fully exploited if constraints violations arise. Another set of simulations are carried out, this time including the constraints, in order to detect and to quantify the violations which occur if the full theoretical reactive power capability would be exploited. The simulation results confirm that the reactive power capability provision lead to both over-voltages and under-voltages occurrence, specifically for some time periods and for highest numbers of controllable resources. The percentages of nodes affected by over-voltages and under-voltages are reported, respectively, in Table 4.5 and in Table 4.6.

TABLE 4.5 – OVERVOLTAGE OCCURRENCE FOR MAXIMUM REACTIVE POWER INJECTION

Nodes [%]	Case 1	Case 2	Case 3	Case 4	Case 5
Jan-Mar – w/day	0	0	0	0	8
Jan-Mar – Sat	0	0	0	0	9
Jan-Mar – Sun	0	0	0	0	9
Apr-Jun – w/day	0	0	0	2	2
Apr-Jun - Sat	4	15	15	23	27
Apr-Jun - Sun	4	16	16	23	27
Jul-Sep – w/day	0	1	1	4	4
Jul-Sep - Sat	2	6	6	17	23
Jul-Sep - Sun	3	15	15	20	27
Oct-Dec – w/day	0	0	0	0	0
Oct-Dec – Sat	0	0	0	1	2
Oct-Dec – Sun	0	0	0	2	5

TABLE 4.6 – UNDERVOLTAGE OCCURRENCE FOR MAXIMUM REACTIVE POWER ABSORPTION

Nodes [%]	Case 1	Case 2	Case 3	Case 4	Case 5
Jan-Mar – w/day	2	10	10	20	23
Jan-Mar – Sat	0	0	0	10	14
Jan-Mar – Sun	0	0	0	2	10
Apr-Jun – w/day	0	0	0	10	17
Apr-Jun - Sat	0	0	0	0	10
Apr-Jun - Sun	0	0	0	0	9
Jul-Sep – w/day	0	0	0	11	18
Jul-Sep - Sat	0	0	0	0	9
Jul-Sep - Sun	0	0	0	0	6
Oct-Dec – w/day	0	7	8	20	22
Oct-Dec – Sat	0	0	0	5	11
Oct-Dec – Sun	0	0	0	0	10

As can be seen from Table 4.5, over-voltages occurrence is higher during the weekends of the hot season (from April to September), when the network experiences high PV production level in combination with low load absorption. These operating conditions, even if they are not considered critical in the baseline scenario, as explained in 4.3.1, push voltage levels in some network areas very close to the upper limit. If the full capability would be exploited, the resulting reactive power injection from the resources increases local voltage levels and then leads to an increment of nodes affected by over-voltages.

On the other side, from Table 4.6, under-voltages occurrence is higher during the workdays of the cold season (from October to March), when the PV production is low but the load absorption is high. Similarly to the previous case, in such conditions the voltage levels in some network areas fall close to the lower limit and the reactive power absorption from distributed resources lowers local voltage levels further, leading to under-voltages.

It is important to point out that also the number of controllable resources affects the violations occurrence; it can be observed that in case 4 and 5 the percentage of nodes affected by over or under voltages is quite higher than in the other cases and, in general, the violations occurrence is spread throughout the whole year with a noticeable increase in the critical periods discussed before. Indeed with higher number of resources is likely that also the share of those connected in the midst or close to the end of their feeders increase too (see Figure 4.2 for reference).For this reason, if such generators provide reactive power, they may increase local constraints violations occurrence, even outside the critical periods identified before. It is evident that most of these violations cannot be tolerated and necessarily require corrective actions; in the last set of simulations the solution of reducing the capability area for solving violations without relying on optimisation and/or OLTC operations is tested. Tap voltage is kept fixed to 1.01 p.u.. Table 4.7 reports the average reduction of the reactive power capability, which allows to avoid constraints violations, expressed as a percentage of the total theoretical capability area for the five case scenarios considered.

TABLE 4.7 – VARIATION OF REACTIVE POWER CAPABILITY DUE TO NETWORK CONSTRAINTS

Variation [%]	Case 1	Case 2	Case 3	Case 4	Case 5
Jan-Mar – w/day	0	-3	-2	-4	-3
Jan-Mar – Sat	0	0	0	0	-1
Jan-Mar – Sun	0	0	0	0	0
Apr-Jun – w/day	0	0	0	-1	-1
Apr-Jun - Sat	-5	-6	-3	-5	-4
Apr-Jun - Sun	-5	-6	-3	-5	-4
Jul-Sep – w/day	0	0	0	-1	-2
Jul-Sep - Sat	-3	-4	-2	-3	-2
Jul-Sep - Sun	-5	-6	-3	-4	-3
Oct-Dec – w/day	0	-1	0	-2	-2
Oct-Dec – Sat	0	0	0	0	0
Oct-Dec – Sun	0	0	0	0	0

It can be seen that in all cases the percentage reduction is very small, reaching a maximum of 6% in the worst ones. Although the percentage values are comparable, the capability reduction depends also on the type of resources which are included in the different cases. For example, capability reduction in case 3 is half the reduction in case 2 (Saturday and Sunday of the second quarter), since the STATCOMs added in case 3 provide a constant capability throughout the whole day and they are connected directly to the primary substation transformers. This means that their contribution gives a sensible increase to the capability area and do not lead to further constraint violations, hence the capability reduction experienced in case 3 has to be addressed to PV generators and the BESS, as in case 2. Basically, the 3% reduction in case 3 may be considered the same of 6% in case 2, but rescaled to a larger capability area. In general it can be seen, during the hot season, that for each case in which the PV generators are the larger source of reactive power capability (Cases 1, 2 and 4) the percentage reduction is higher than in the other cases, since PV production sometimes lead to local over-voltages which can be solved with a reduction in reactive power output of the involved generators. The aspects described so far can be easily observed in Figure 4.21, which reports the theoretical capability areas of case 3 and case 5 scenarios, calculated for Sunday of the second quarter, with the corresponding reductions highlighted.

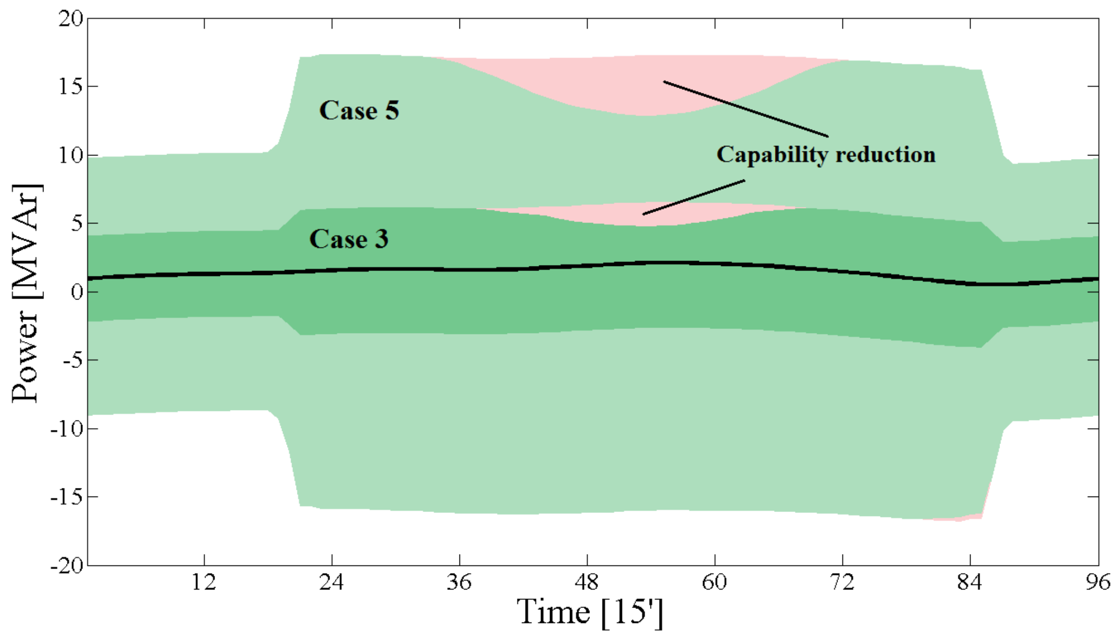


FIGURE 4.21 – PICTORIAL COMPARISON OF REACTIVE POWER CAPABILITY REDUCTION FOR CASE SCENARIOS 3 AND 5

The picture shows that the magnitude of the capability reduction is proportional to the total theoretical area, since the reactive power capability increases steadily from case 1 to case 5. Furthermore, it is clearly visible that the reduction is limited to the central part of the day, so the PV production still represents the strongest constraint for reactive power capability exploitation.

As for the baseline scenario, the line loading is evaluated also in presence of reactive power modulation. Figure 4.22 reports the line loading distribution in branches, calculated in Sunday of the second quarter for the case 5 scenario. Even if a small increase in line loading is observed, most of the branches show an average loading of 5%, and the maximum loading does not exceed the 50% of the branches capacity.

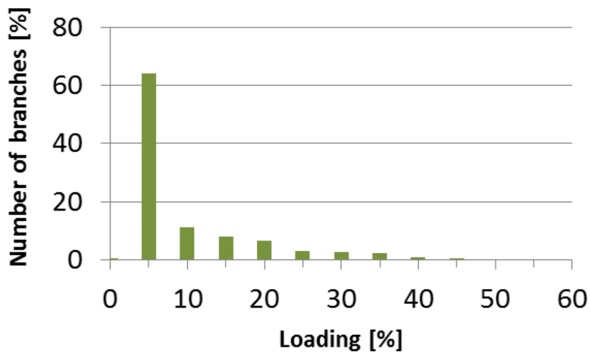


FIGURE 4.22 – LINE LOADING DISTRIBUTION IN BRANCHES, SUNDAY, SECOND QUARTER (APR-JUN), CASE 5 SCENARIO

The results presented in this section allow evaluating the magnitude of the reactive power capability available at the primary substation node for the considered case scenarios. Furthermore, its impact on network constraints is assessed revealing that a full exploitation of reactive power capability is not always possible (without optimization). For this reason, the equivalent reduction of the capability area is calculated in order to evaluate how much reactive power flexibility can be exploited without violating network constraints.

4.3.4 SIMULATION OF THE PARAMETRIC BIDDING CURVE FOR ACTIVE POWER FLEXIBILITY

The third set of simulations focuses on the calculation of the active power parametric bidding curve, following the process described in 0.

Some additional assumptions are considered in simulation phase, in order to simplify the calculation:

- BESS is modelled with a usable range for active power equal to 0.5 MW;
- BESS is modelled as an infinite capacity storage (no charge constraints considered);
- active power steps have a fixed duration of 15' and a fixed amplitude of 0.5 MW;
- only downward regulation is selected for generation plants.

Table 4.8 summarizes the selected flexibility cost figures:

TABLE 4.8 – FLEXIBILITY COST FIGURES

Type	Cost (Euro/MW)
PV reduction	30
BESS power absorption	50
BESS power injection	60

Figure 4.23 shows an example of the parametric bidding curve based on the previous hypotheses; it refers to case 3 scenario set-up and to the second quarter generation profiles.

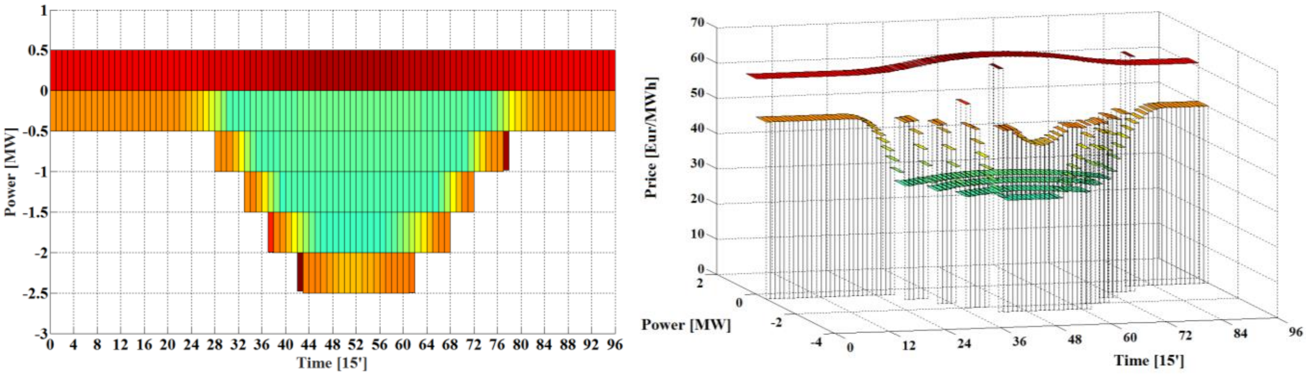


FIGURE 4.23 – EXAMPLE OF PARAMETRIC BIDDING CURVE, SECOND QUARTER (APR-JUN), CASE 3 SCENARIO

In Figure 4.23, each elementary rectangle represents an active power bid: they can be positive (upward regulation) or negative (downward regulation). The colour scale depicts the difference in price, from light green (lower price) to dark red (higher price), as can be seen in the 3D picture on the right.

Following the adopted hypotheses, the upward regulation is completely up to the battery storage, the power injection of which has the highest price, while the downward regulation can exploit the PV plants power reduction, for the central part of the day, and the battery storage power reduction during the night time. The battery storage can be exploited for additional regulation during the day light hours but with a higher bid price (compared to PV plants), as represented by the orange outline around the green area. Figure 4.24 and Figure 4.25 show the parametric bidding curves calculated for each of the case scenarios presented in 4.2.3; the time period selected is Sunday of the second quarter. The colour scale ranges from dark blue (lower prices) to light blue-green (higher prices).

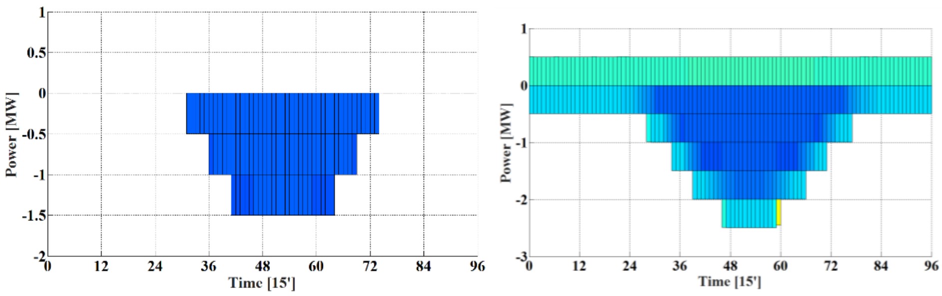


FIGURE 4.24 – PARAMETRIC BIDDING CURVES, SECOND QUARTER (APR-JUN): A) CASE 1 AND B) CASE 3 (SAME AS CASE 2)

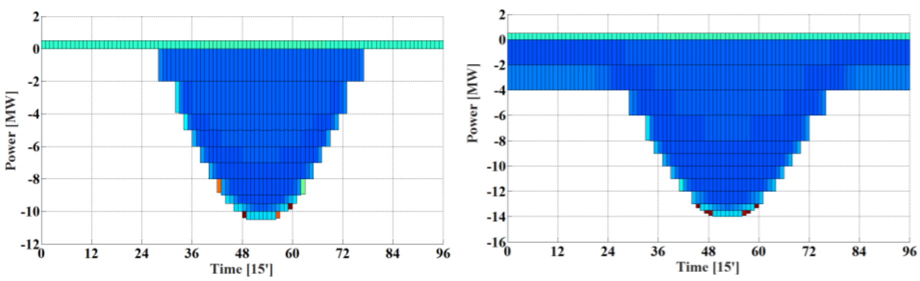


FIGURE 4.25 – PARAMETRIC BIDDING CURVES, SECOND QUARTER (APR-JUN): A) CASE 4 AND B) CASE 5

Similarly to the reactive capability analysis, the higher the number of resources the broader is the flexibility area, specifically during the daytime, when PV production is higher; the increment is mainly oriented towards the downward regulation due to the hypotheses made but, if power reserve band would be considered for generators, a suitable flexibility area for upward regulation could be easily achieved. It should also be noted that the bid price for downward regulation drops as more as the number of flexible resources increase, resulting in an evenly price distribution for case scenarios 4 and 5 (Figure 4.25). In such cases, the exploitation of battery storage flexibility is not worth for downward regulation due to its limited range and its high price.

Despite the simplified assumptions introduced in these simulation (more complex modelling would be necessary to get closer to realistic operating conditions), the achieved results show that also in the most challenging condition (Case 5 scenario) and with OLTC control disabled, no major voltage or current constraints violations were observed.

The results presented in this section show that the demonstrator network can provide suitable active power flexibility range with a limited impact on the network operations, without violating voltage and current constraints. These results should be considered only as a preliminary assessment to be used as a reference for defining improved simulation models, which better describe the operating scenarios actually implemented in the networks in which active power flexibilities exploitation is allowed.

4.4 PRELIMINARY CONCLUSIONS

The results achieved with the simulations and presented in this chapter 4 give a full picture of the potential of the demonstrator network in providing suitable reactive and active power flexibilities, which can be exploited for supporting service provision to the transmission network. Furthermore, the simulations provide a detailed description of the baseline operating conditions, as well as the impact of different operating conditions on the network, which represent the background for the future field tests of the Italian demonstrator, within the next activities of WP6.

The potential range of active and reactive power modulation of the network is determined for different resources set-ups (case scenarios), showing that the resulting capabilities can virtually allow very high degrees of freedom for power exchange at primary substation.

The considered case scenarios allow to evaluate which resources set-ups can actually provide a suitable range of flexibility and to identify the limitations of using different types of resources. In particular, it is evident that the predominance of PV plants in the demonstrator network can result in wide capability areas. However, this capability is contained, basically, in the hot season and in the central part of the day which underlines the need of dispatchable generators and dedicated assets (STATCOMs and battery storage) for extending the power modulation also to night time and, in general, for obtaining longer capability areas over the year.

Case scenarios analysis showed the overall potential of the demonstrator network in terms of flexible resources; the case scenario corresponding to the actual demonstrator set-up (four PV generators, STATCOM and BESS) can theoretically provide a modulation range with the same magnitude as the power exchange profiles observed for baseline scenario, while the case scenario 5, which considers all the connected generators, can provide a modulation range three times larger. These results demonstrate that a suitable amount of power flexibility is already present in the demonstrator network and could be potentially exploited once all the connected resources are involved and the remaining technical constraints are removed.

The impact of the flexibilities exploitation on the network constraints violations is evaluated as well, showing that the violations occurrence can increase in such circumstances but, in general, they superimpose to already close-to-limit operating conditions, mainly due to seasonal issues with PV plants production. It has to be noted that violations may be critical only for full exploitation of all the connected resources flexibilities, which can be far more than the actual flexibility needs (due to very wide range of power modulation achievable in such conditions). Anyway, the reduction of the aggregated flexibility area in order to avoid voltage constraints violations does not exceed 6% of the total area, allowing enough range for power modulation maintaining secure operations of the distribution network.

Apart from these extreme operating conditions, no major voltage or current constraints violations are observed. This is in line with the adopted network planning philosophy, which relies on a reinforced smart and active system, instead of a passive one. Additionally, in the considered portion of the network, many of the largest generators are connected close to the primary substation and so their operations have a slight impact on voltage levels.

Such characteristics, driven by other factors than the purpose of exploiting distributed power flexibilities, turn out to be favourable (within the Italian demonstrator) for the envisioned network operations, focused on supporting the provision of active and reactive power-based services to the transmission network. Potential limitations may come from constraints related to OLTCs operations: this aspect will be evaluated more in details in deliverable D6.5 [1].

5. JOINT ANALYSIS OF SIMULATION TOOLS

The scope of this chapter is to outline a common view of the simulations presented so far, focusing on how the different approaches can address the WP6 objectives, complementing each other, and how their jointly exploitation may contribute to the goals envisioned by the EU-SysFlex project.

5.1 COMMON VIEW OF SIMULATIONS WITHIN WP6

Previous chapters explained in detail the specific scopes and objectives of German and Italian simulation approaches, presenting their technical characteristics and the tests carried out for the purposes of the demonstrators' activities. In the following, the achieved results are briefly reviewed underlining the impact they have on WP6 objectives.

For the German demonstrator, simulation tests aimed at analysing the impact of different reactive power control modes and asset behaviours in HV distribution network on the status of EHV transmission network; in parallel, the simulation environment was exploited to evaluate preliminary optimisation results. These activities were carried out both with simulated data and with historical data coming from a real voltage collapse event.

The test results show that the adopted simulation approach allows to successfully identify which reactive power control modes are better suited for achieving a more effective local and global voltage stabilisation; they demonstrate that the reactive power flexibility optimization from the DSO offers the best results in this sense. The system and methods developed within the German demonstration show promising application in exploiting local reactive power flexibility as a systematic way to sustain the local voltage stability; the inclusion of DERs from the MV distribution network can further support this concept, increasing the available flexibility. No major violations are observed for any of the control modes tested, making them potentially applicable without risk of affecting negatively the optimal operations of distribution network.

For the Italian demonstrator, simulation tests first aimed at determining the actual range of total active and reactive power capability of the demonstrator network, to investigate the scalability of flexibility potential for different network scenarios and different types of resources, and to evaluate the impact of flexibilities exploitation on network constraints.

The test results show that the adopted simulation approach allows to calculate the potential range of active and reactive power flexibility for different resources set-ups (case scenarios), showing that the resulting capabilities can virtually allow very high degrees of freedom for power exchange at primary substation. Through case scenarios analysis, it is possible to identify which resources set-ups can actually provide a suitable range of flexibility and what are the corresponding limitations: in particular, the predominance of PV plants results in wide capability areas but their full exploitation in the hot season can cause voltage violations; on the other side, the exploitation of dedicated assets (i.e. STATCOMs in this case) can extend the power modulation in other time periods and can potentially overcome the issues related to local voltage violations. Simulations show also that voltage violations may occur only for the full potential reactive flexibility exploitation, but they can be easily be avoided in return for a small reduction of flexibility area. Excluding such extreme operating conditions, no major voltage and current constraints violations are observed, so reactive flexibility provision in the Italian demonstrator can be done without creating harmful operating conditions for the distribution network.

Concluding, it can be seen that both German and Italian simulations contribute to the pursuing of an **optimal state for the distribution network**, **considering potential TSOs requests**, helping effectively to identify better control strategies for distributed resources, maximizing flexibility exploitation in order to potentially address needs of the transmission network, without affecting negatively the operating conditions for the distribution networks.

From the point of view of the coordination and cooperation between TSO and DSO, in the German case, the demonstrator set-up contains also a dedicated communication interface, for easily sharing flexibility range data with TSO, and its operations are tested in simulations; in the Italian case, since the demonstrator relies on the existing communication interface, simulations address only the calculation of set-points representing the available flexibility range. In this case it is evident that simulations support the **improvement of DSO-TSO interface** in a limited extent. Anyway, it should be noted that this objective is specifically addressed by communication tools, which are presented in deliverable D6.4 [1].

The schematic in Figure 5.1 pictures how simulations can be linked with WP6 objectives:

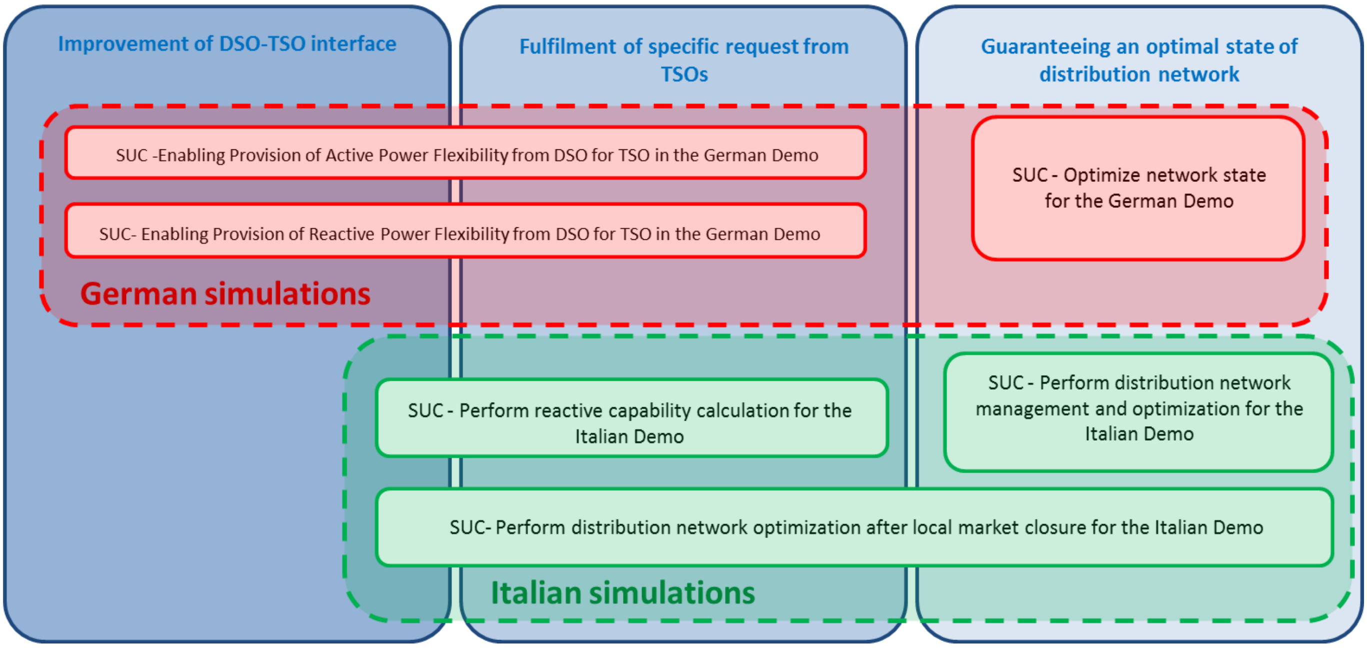


FIGURE 5.1 – LINKS BETWEEN SIMULATIONS, SYSTEM USE CASES AND WP6 OBJECTIVES.

This figure is derived from a similar one, included in deliverable D6.1 [1] , which links each System Use Case developed within Task 6.2 to the of WP6 objectives. In this specific case, some of the functionalities described in the SUCs are the same functionalities exploited by the simulations: hence, they represent the link between simulations and SUCs which can be extended also to simulations and WP6 objectives. Anyway, it is important to underline that network simulations described here may not realize the system processes describe in SUCs in their entirety. Indeed, in the Italian case, the algorithms implementing the functionalities necessary for the simulations are extracted from the SCADA system and installed in a dedicated simulation environment, which is not intended to fully replicate the system processes described in the SUCs. In the German case, the philosophy behind simulation analysis is focused toward the emulation of the system processes described in the SUCs and so SUCs and simulations are strictly linked.

5.2 HOW SIMULATION APPROACHES CAN BE EXPLOITED JOINTLY

In the previous parts of this document, the simulation approaches adopted by German and Italian demonstrators are reviewed in every aspect, describing their specific features, and comparing them in order to highlight the specificities that made them different. In this section, the two approaches are analysed from a different point of view in order to identify how they can be exploited jointly, complementing each other, and so translating the concept of simulations into a holistic perspective.

German simulations are focused on investigating the efficiency and the reliability of the novel HV DER coordination approach for handling possible foreseen congestions and control voltage profiles of the EHV transmission grid; this goal is achieved testing different reactive power control strategies, using historical data from a real voltage collapse event. In brief, German simulations address the need of identifying suitable strategies to exploit HV flexibility in a meshed grid for efficiently support congestion management in EHV transmission network.

Italian simulations are focused on investigating the actual flexibility potential of a radial MV distribution network, in order to assess how it can support ancillary service provision to HV transmission network; this goal is achieved testing different network scenarios and controllable assets for calculating the actual flexibility range which could be exploited without violating the distribution network constraints. In brief, Italian simulations address the need of identifying suitable and reliable flexibility ranges from MV networks to efficiently support ancillary services in HV transmission network.

The physical set-ups can be linked together by the means of primary substations, as actually happens between HV and MV networks: in German demonstrator, MV loads and generators are aggregated at primary substation level and considered as equivalent HV resources with their own normalised profiles while in Italian demonstrator, HV network is considered as a slack node with specific power and voltage set-points.

Regarding the information exchange, a bi-directional data flow could be established at primary substation interconnections, realising a bijective link between the inputs and outputs of the simulation tools applied to each set-ups: if a bottom-up data flow is considered, the Italian demonstrator could provide aggregated active and reactive power profiles with a flexible range of variation; the German demonstrator could exploit these flexible profiles as the corresponding MV network acts as a virtual HV flexible generator, coordinating it together with other resources in order to provide suitable P-Q flexibility to the TSO extra high-voltage networks; conversely, if a top-down data flow is considered, German demonstrator could identify new operating conditions, for meeting specific EHV network needs for example, which can be translated in power set-points at primary substation level, i.e. at the slack node of MV network; the Italian demonstrator could treat these set-points as constraints in the optimisation process applied to MV distribution network.

The correspondences outlined above could be exploited within a single simulation approach; indeed, the results coming from flexibility range assessment in Italian simulations can be exploited in the German simulations, in which different planning and coordination action are tested, translating in corresponding operating conditions of MV network, which may be tested again within Italian simulations.

In brief, the results coming from simulation tests of one demonstrator could be exploited in the simulation test of the other one and vice versa. Alternatively, both simulation approaches could be applied jointly in a single analysis, returning valuable results for both the demonstrators.

Based on the holistic perspective envisioned in D6.1 [1] and presented in D6.6 [1] , and also including market aspects and the aggregation of LV asset flexibilities, the three WP6 demonstrators can virtually interlink in a single equivalent set-up, as pictured in Figure 5.2.

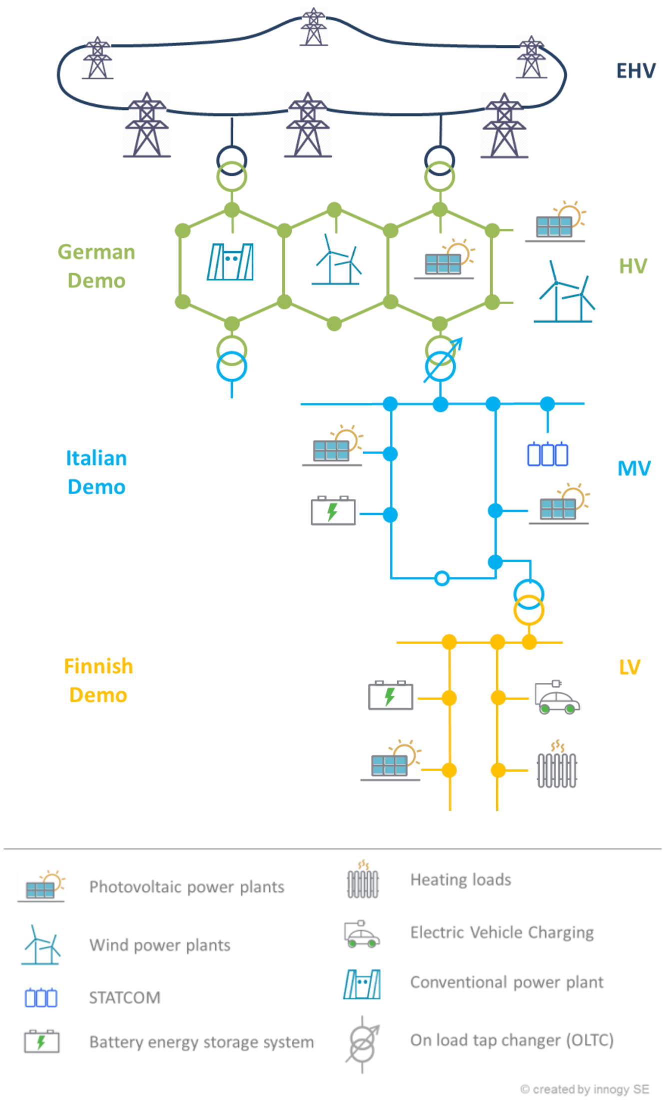


FIGURE 5.2 – COMPLEMENTARITY OF THE DEMONSTRATORS IN ONE THEORETICAL GRID INFRASTRUCTURE (FROM D6.6)

As a general concept, simulation tests can be considered as investigation processes of specific operating conditions which cannot be replicated and/or tested in the physical set-ups of the demonstrators, regardless if they are applied to networks, markets or other operational scenarios. Furthermore, it can be presumed that bi-directional data flows can be established every time a physical interconnection between two different systems take place, being necessary to guarantee that both the systems can be managed efficiently on their own, while maintaining the link between them. Using such an approach provides also an inherent resilience in cases of no communication or other faults since the different voltage levels can then also be operated independently. Based on these assumptions, it can be stated that active and reactive power flexibility information coming from simulation analysis applied to one system could be potentially used by the linked system for its own simulation analysis, regardless the type of simulations tests carried out. Indeed, for example, the PQ flexibility maps provided by an aggregator to a DSO, as a result of the aggregation of LV flexible resources at secondary substation, could be modelled as a virtual MV flexible generator and included in a MV grid model to be used in distribution network simulation tests.

Concluding, if the results from simulation tests carried out within each WP6 demonstrator, regardless of the operational scenarios considered, could be complementary with the results from simulation tools/approaches applied to the other demonstrators, it is possible to realize a global simulation analysis of the virtual set-up, in line with a holistic view of the European electricity system.

6. CONCLUSIONS

This deliverable presents the grid simulation approaches and simulation tools adopted within the WP6. Furthermore, it gives preliminary results of the relevant test cases and scenarios achieved from these simulations, which are modelled upon the real demonstrator frameworks.

The objective of these simulations is to explore the new operating conditions that the demonstrator networks have to face, if distributed assets flexibilities are activated to provide ancillary services to the TSO. The general need of testing new operating scenarios in order to "analyse the opportunities arising from decentralised flexibility resources connected to the distribution grid to serve the needs of the overall power system" is in common with all the demonstrators. However, the ways pursued to address this need are different and reflect the specific features and background of each demonstrator. Each "simulation philosophy" has been analysed in the context of the corresponding demonstrator and then compared with the others in respect to the fulfilment of the WP6 objectives.

The simulation concepts have also been analysed in connection with the other tools families addressed by Task 6.3, namely communication tools, forecast tools and optimization tools, in order to identify what simulation tests mean within each specific demonstrator context and what objectives they are intended to address in respect to the other tools. From this analysis, it becomes evident that, for Finnish demonstrator, testing new operating scenarios require a detailed analysis of market optimisation and forecast of resources: for this reason, network simulation tests are not considered. Therefore only the simulation approaches adopted within German and Italian and the corresponding preliminary tests are described in detail in this deliverable.

Within the German demonstrator, the simulations were carried out through a dedicated simulation tool, the scope of which is to virtually replicate the full control chain developed for the demonstrator set-up, including forecast, communication and optimization algorithms. The goal of the German demonstrator is to show how the coordination between DSO and TSO for flexibility exploitation may be more efficient in respect to the actual approach, providing suitable P-Q maps and P and Q flexibility ranges that can be accessed by the TSO and improving the communication between DSO and TSO. The German simulation tool was used to test the proper functioning of the developed algorithms and then it was applied to a real case of voltage collapse occurred in the German transmission network. Through the simulation tool it was possible to perform ex-post tests, evaluating how different flexibility management procedures would have affected the transmission network voltage profiles, potentially solving the voltage collapse issue. The achieved results confirm the soundness of the demonstrator set-up and the reliability of the developed algorithms.

Within the Italian demonstrator, the simulations were carried out through a custom one-off simulation environment in which the SCADA calculation algorithms are implanted: the scope of this arrangement is to exploit the SCADA functionalities in off-line operations and apply them to different operating scenarios. The goal of the Italian demonstrator is to show how the already connected DERs plus some dedicated assets (BESS, STATCOM) may be managed and optimised locally by the DSO, providing aggregated reactive power capability and a cumulative parametric curve (energy/cost) for active power to the TSO at primary substation. The simulation tests carried out for the Italian demonstrator returned the potential range of flexibility achievable from its network in five operating scenarios characterized by different types and increasing numbers of flexible resources. Additionally, the range of flexibility which could be actually exploited without violating the distribution network constraints was also assessed. These results confirm that the concept of aggregation of flexible resources at distribution level can be applied in the Italian national scenario and that the participation of all the distributed flexible resources already connected may allow to have a suitable flexibility range for meeting the needs of both TSOs and DSOs.

The simulation approaches and the corresponding results were reviewed from an holistic point of view, analysing how they contribute to the Work Package 6 objectives: since simulation tests emulate in some way the optimization processes, it is reasonable to state that they contribute to the pursuing of an optimal state for the distribution network; furthermore they also support, indirectly, the fulfilment of specific request from TSOs by analysing that the flexibility range for different operating conditions is suitable for the envisioned TSO needs. Furthermore, based on the single theoretical grid infrastructure presented in D6.6, jointly exploitation of both German and Italian simulation approaches is analysed: Italian demonstrator network can be connected to the German high voltage distribution network and treated, from a simulation perspective as a virtual flexible HV generator. The results of network simulations carried out in Italian demonstrator could be shared with the German simulation tool allowing to perform a larger-scale simulation; then, the outcomes of the simulations of HV distribution network carried out by German simulation tool could be used as a feedback for the Italian simulations, by the means of power set-points at HV/MV primary substation. From this perspective it may be possible to carry out more complex analysis with a higher level of accuracy.

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