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Opportunities arising from Decentralized Flexibility Resources to serve the Needs of both DSOs and TSOs - Results and Recommendations from the Demonstrators

D6.10

EU-SysFlex

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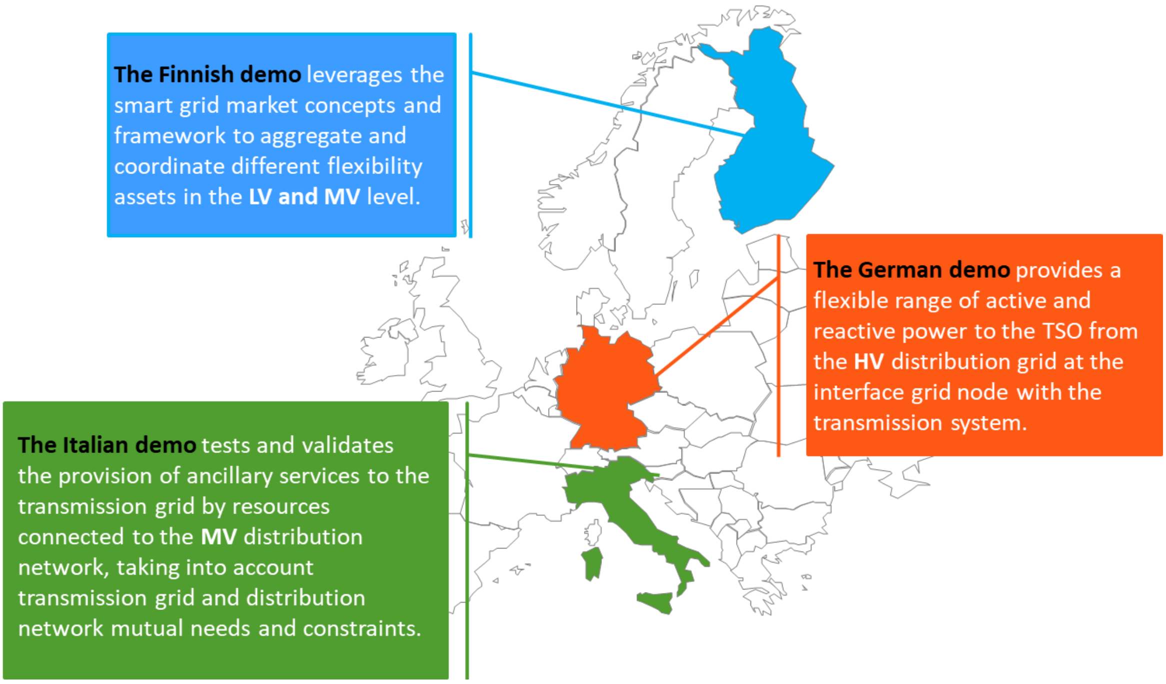
ABBREVIATIONS AND ACRONYMS

AMR	Automatic Meter Reading
BESS	Battery Energy Storage Systems
DER	Distributed Energy Resources
DERMS	Distributed Energy Resource Management System
DSO	Distribution System Operator
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	
FCR-N	Frequency Containment Reserve for Normal operation
HV	High Voltage
ICT	Information and Communication Technologies
LV	Low Voltage
mFRR	manual Frequency Restoration Reserves
MV	Medium Voltage
OLTC	On-Load Tap Changer
P	Active Power
PV	Photo-Voltaic
Q	Reactive Power
RES	Renewable Energy Sources
SCADA	Supervisory Control and Data Acquisition
STATCOM	Static Synchronous Compensator
TSO	Transmission System Operator
WP	Work Package

EXECUTIVE SUMMARY

Today, the energy supply within the European energy system is undergoing significant changes due to the addition of renewable energy sources (RES), which are mainly integrated in distribution grids. As a result, it is followed by increasing decentralization and complexity of the power supply. This inevitably leads to high probability of widespread technical challenges such as line overloads, reverse energy flows, unforeseen congestions and sudden voltage violations. Nevertheless, renewable generation units are gradually replacing conventional power plants due to relatively low energy cost and minimal harmful impact on the environment. In addition, the renewable resources are characterized by a high level of fluctuation in power supply, which is crucial for grid operators such as DSOs and TSOs. In this regard, it becomes necessary to implement innovative system solutions, as well as effective measures and tools for the optimisation of the energy system with high share of RES, including further development in the energy market. This is the goal of EU-SysFlex.

Within EU-SysFlex, three demonstrators located in Germany, Italy and Finland have **analysed the opportunities arising from decentralized flexibility resources connected to the distribution grid to serve the needs of the overall power system.** The three demonstrators have been set up in order to show how assets connected to the distribution level can help alleviate constraints and solve scarcities on the transmission and distribution level.



The primary objective was to analyse and test the exploitation of decentralized flexibility resources connected to the distribution grid, while respecting the needs of both DSOs and TSOs. Due to the current policies for the decarbonisation of the energy systems, the installed capacity of RES is increasing. The distribution system need to integrate an important share of it while, at the same time, having to guarantee the security and resilience of their systems. A consequence of this is their need for sufficient flexibility in their system operation in order to avoid congestions and constraints violations.

Based on the results of these demonstrators, a total of 13 key messages are drawn based on the evidences proved by the 3 field tests:

- System operators need to find new solutions to deal with the increasing share of renewable energy resources and the electrification of the heating and mobility sector.

- Today's low observability of the distributed generation plants behaviour and the distribution system hinders an efficient integration of renewable energies in system operation. An increased system observability in distribution grids shall be achieved.

- The increasing complexity of the system requires to test and integrate new assets. It is crucial to foresee a proper remuneration mechanism for these investments in order to reach an advanced smart grid infrastructure

- System operators need to harness new opportunities arising from decentralized flexibility resources to increase the efficiency of a secure system operation.

- The role of the DSO is evolving more and more to an active system operator in all voltage levels. The DSO shall therefore be allowed to use all flexibility technologies connected to its system to fulfil its responsibilities.

- The DSO needs to be involved in operational planning and in the procurement of congestion management and voltage control services, given that most of the flexibility resources are connected to the distribution grid. Therefore, an increased DSO/TSO coordination is needed.

- For an efficient and effective DSO/TSO coordination, the process for flexibility selection and activation shall be as far as possible automated and based on the following principles:
    - Every system operator is responsible for its own grid.
    - Every system operator predicts the available flexibility potential in its own grid.
    - System operators from connected grids are being informed about available flexibility potential.
    - Flexibility selection and activation for congestion management and voltage control is carried out by the system operator where the flexibility is connected to.
    - Both TSO and DSO needs and constraints are taken into account.

- Decentralized optimization approaches based on the optimization principle “local before regional” shall be applied for flexibility selection as they are highly resilient, efficient and secure

- A market based approach for flexibility usage should be applied unless low liquidity and strategic gaming prevents it.

- Forecasting, optimization, control logics as well as reliable communication systems are needed in order to enable the utilization of assets in the flexibility markets.

- To unlock the potential of new and technically feasible solutions, the modification of the regulatory or market framework is required eliminating regulatory and market barriers. This is only possible with the support of policy makers, regulators and in cooperation with flexibly service providers and prosumers.

- The data management principle “data thrift” is essential and at the same time was proven to be feasible and effective if based on three principles:
    1) grid data always stays in the sphere of the respective system operator.
    2) grid impact analysis remains the responsibility of the respective system operator.
    3) data exchange is aggregated as much as possible to reduce complexity.

- Overall, the distribution system demonstrators prove how flexibilities in the distribution grid can be used efficiently to meet the requirements of both DSOs and TSOs

Based on the key messages recommendations to system operator, policy makers and regulators, as wells as market operator are derived. The results and conclusions presented in this report are based on facts created by real field tests[1] as part of the EU-SysFlex project.

[1] Detailed results of the three demonstrators can be found in the specific demo reports [D6.7] [D6.8] and [D6.9].

1. RESULTS OF EU-SYSFLEX DEMONSTRATORS IN THE DISTRIBUTION SYSTEM

1.1 OVERALL OBJECTIVES AND VISION OF EU-SYSFLEX DEMONSTRATORS IN THE DISTRIBUTION SYSTEM

The members of the European Union committed themselves to cover at least 50 percent of electricity consumption with renewable energy sources by 2030. In order to integrate these amounts of renewables, a flexible, responsive and dynamic power system is needed for the whole of Europe. The EU-SysFlex project seeks to enable the European power system to utilise efficient, coordinated flexible resources in order to integrate high levels of Renewable Energy Sources (RES). The sixth Work Package (WP6) about “Demonstration of flexibility services from resources connected to the distribution network” **analyses the opportunities arising from decentralized flexibility resources connected to the distribution grid to serve the needs of the overall power system. It emphasizes the coordination between distribution system operator (DSOs) and transmission system operator (TSOs)**, by means of three demonstrators located in Germany, Italy and Finland. The three demonstrators have been set up in the EU-SysFlex project in order to show how assets connected to the distribution level can help alleviate constraints and solve scarcities on the transmission and distribution level.

The primary objective of this Work Package was to analyse and test the exploitation of decentralized flexibility resources connected to the distribution grid, while respecting the needs of both DSOs and TSOs. Due to the current policies for the decarbonisation of the energy systems, the installed capacity of RES is increasing. The distribution system need to integrate an important share of it while, at the same time, having to guarantee the security and resilience of their systems. A consequence of this is their need for sufficient flexibility in their system operation in order to avoid congestions and constraints violations.

At the system level, the amount of traditional flexibility resources, historically provided by conventional generation connected to the transmission network, decreases. Therefore, there is an increasing need for flexibility resources in the distribution grid in order to guarantee security and resilience in the transmission and distribution system operation. According to this, three sub-objectives were identified:

- Improve the TSO-DSO coordination;
- Provide ancillary services to the TSOs from flexible units connected to the distribution grid;
- Investigate how these flexibilities could meet the needs of both TSOs and DSOs.

By means of the three EU-SysFlex demonstrators in the distribution system, we have analysed and tested the opportunities arising from decentralised flexibilities resources to serve the overall system needs. Figure 1.1 shows the location of the three WP6 demonstrations and gives a short overview of their main focus.

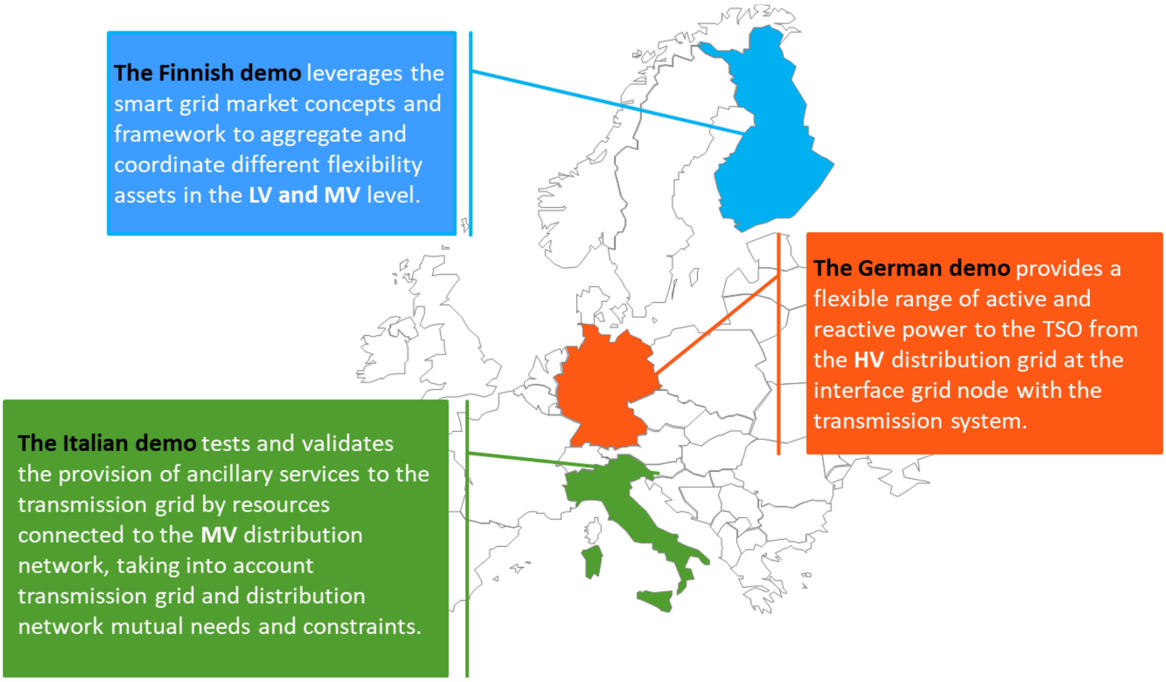


FIGURE 1.1 DEMONSTRATORS OF WP6 EU-SYSFLEX

Objective of this deliverable

This deliverable aims to provide a clear overview of the conclusions and recommendations drawn based on the results of the field tests carried out in Germany, Italy and Finland.

In the following chapters (1.2, 1.3 and 1.4), the main high-level results of the demonstrators are presented (more detailed results can be found in the respective demonstrators' deliverables [D6.7], [D6.8] and [D6.9]) as well as the joint key messages (chapter 2). Based on the key messages recommendations to system operator, policy makers and regulators, as well as market operator are derived (chapter 3).

The results and conclusions presented in this report are based on facts created by real field tests as part of the EU-SysFlex project.

1.2 RESULTS OF THE GERMAN DEMONSTRATOR

Motivation

It is expected that by 2030 the share of RES-E will have increased up to 65%. There is already a high RES-E share (in 2020 ~45% RES-E in Germany and since 2017 more than 100% in the demo region), especially wind power in north-eastern Germany, which causes substantial redispatch measures to avoid overloading transmission and distribution assets. In 2017, congestion management costs reached a record of €1.4 billion.

The redispatch potential in the transmission grid is reaching its limits due to the minimal capacity of conventional power plants and decreasing level of installed capacity in conventional plants. Therefore, emergency measures are used to curtail RES-E in the distribution grid. Redispatch potential can be increased by utilising DER and RES-E in the distribution grid. This exacerbates the need for more efficient and coordinated congestion management processes for TSOs and DSOs. Otherwise, the DSOs may make use of congestion measures, which could be counteracting to the TSO measures.

There is also an increasing requirement for reactive power management. A coordination mechanism is therefore needed that would enable the TSO to use reactive power flexibilities from the distribution grid.

Objective

To tackle challenges for DSOs and TSOs the needed coordination process should be efficient. Therefore, coordination processes need to satisfy the requirements for congestion management and voltage control. The Objectives of the German demonstration were not only to set up new processes but also to develop tools that enable the automation of voltage control and reactive power management.

Innovation & Key Results

The German Demonstration proved the concept of the defined new processes for TSO/DSO-coordination together with the developed DSO process to include RES-E from distribution grid in active and reactive power management. Additionally, the feasibility of the combined active and reactive power grid optimisation in an automated process was proven. For proving the feasibility of process and the functionalities of the developed optimisation tools, an accurate forecast of RES feed-in and load was imperative.

Proved Benefits

The developed grid optimisation and processes allow schedule-based congestion management including balancing of adjusted infeed and load. This reduces the amount of needed frequency control reserve and allows the procurement of cost efficient flexibilities. For congestion management and voltage control, the crucial factor is the sensitivity to ease the need, means the effectiveness, in the grid. Although regulation for reactive power management and active power management is different, the benefits for congestion management and voltage control are similar. In addition, the German demonstration proved the benefits of combined optimisation of active and reactive power, first in reducing the overall need of active power flexibilities in distribution grid and second in reducing grid losses. Therefore, this approach enables facilitating higher potential of available flexibilities from DSO for TSO congestion management. To summarise it, the German demonstration has shown its advantages for a more efficient operational planning for DSO and TSO.

1.3 RESULTS OF THE ITALIAN DEMONSTRATOR

Motivation

The Italian distribution networks are characterized by a high penetration of RES that can cause voltage control issues and congestions. Only in 2019, there was an increase in distributed generation connected to the network of E-Distribuzione of 58.7 thousand plants and 99% of them are connected to MV/LV grid. Already in 2019, the overall figure is 818,764 production plants connected to the E-Distribuzione network for a total power of 28.9 GW. In this case, the amount of distributed generation directly connected to the MV and LV networks is relevant and equal to 24.4 GW.

With these numbers, more and more advanced control solutions must be adopted for the management of distribution networks both for improving their operation and to improve their coordination with the transmission network. This is crucial in the current situation where, due to the increase in share of RES and the decrease in conventional generation capacity, there is a scarcity of resources in transmission network able to provide ancillary services.

The possibility of distributed resources to offer services to the transmission network represent both an opportunity and a challenge for the DSOs and, in this new scenario, they have to facilitate the participation of local resources to different ancillary services provision to the transmission network.

The control of the power flows at DSO/TSO interface becomes crucial also to satisfy the need of the DSOs to operate their networks correctly. The increase of DERs can represent an opportunity to find the best ways to exploit them also for better managing the distribution networks, above all in emergency contexts.

Objective

The Italian Demonstrator has explored the evolution of distribution network infrastructure, by integrating the monitoring systems with advanced smart grid devices, in order to encourage the ancillary services provision to the transmission network taking into account both TSO and DSO needs and constraints. This has been possible thanks to: tools, systems and devices development and integration within the DSO infrastructure; the implementation of developments aimed at improving the coordination between the TSO and the DSO; the improvement of the distribution network observability and forecasting systems; the optimization of the distribution network operations, by exploiting DERs and DSO assets.

Innovation & Key Results

The Italian demonstrator can be understood as a Proof of Concept of an efficient and automated coordination process between DSO and TSO. Its main innovative aspect consists in including RES, Storage and also STATCOM (the first one connected to the E-Distribuzione grid) in the congestion management, voltage regulation and Reactive Power management of both transmission and distribution networks.

This is possible thanks to a more accurate RES feed-in and load forecasting and also to the development of automated tools for Network State Analysis, Network Optimization and Reactive Power Management.

Proved Benefits

A first important benefit deriving from the developments made within the demonstrator consists in the improvement of the observability of the resources connected to the distribution network.

The advanced forecast, combined with the network state estimation and the function for the calculation of reactive power capability, demonstrate that the DSO can provide to the TSO reliable information on the amount of power, in particular reactive, that can be provided by local resources. Besides, the improved observability of the distributed resources supports also the network state estimation contributing to a better management of the network. Results coming from offline and real-time tests demonstrate the capability of the DSO to support the TSO requests.

Considering also that the STATCOM is a new device for the E-distribuzione infrastructure, the project tests have represented the opportunity to demonstrate that its action is successful. In terms of reactive power capability management it provides the following benefits: limitation of reactive power flows at the Primary Substation; meeting TSO requests at TSO/DSO interface; support to Voltage Control; power factor compensation.

1.4 RESULTS OF THE FINNISH DEMONSTRATOR

Motivation

The RES-E of wind and solar represents in Finland ca. 13% of the electricity production. This share has increased exponentially and the development is expected to continue and accelerate. The growth challenges the transmission level frequency management of the Finnish power system where market based procedures have been applied. Controllable flexibility assets and their successful operation is crucial. More flexibilities are needed. Assets connected to the low voltage grid are so far an untapped resource for ancillary services tackling the needs of the TSO and there lies a vast potential for providing flexibility to the power system. The same assets also represent a resource of reactive power. The reactive power characteristics of the power system have drastically changed and new kind of reactive power management are to be developed. A market-based approach can be an answer to this need.

Objective

The objective of the Finnish demonstrator was to increase especially the use of market-based concepts and virtual power plants to support the operation of the transmission and distribution networks. The innovative aspect was to integrate small, so far untapped flexible assets in medium and low voltage grid, to the aggregation processes and offer these assets to the TSO ancillary (frequency) services and for DSO's needs. The flexible assets in the Finnish demonstrator were an industrial-sized BESS, customer- and office-scale batteries, EV charging systems and residential electricity storage heating loads. Active as well as reactive power were applied as flexibilities.

Innovation & Key Results

In the Finnish demonstration a set of forecasting/optimization tools were developed to estimate the available flexibility of the LV/MV assets for TSO ancillary services. Technical proof of concept was accomplished of distributed flexibility resources BESS (residential, office and industrial scale), PV and EV charging points. These assets were controlled according to market actions. In addition, two BESS (industrial and office scale) were operated in real-life TSO market. Also, a technical proof of concept was developed for a new market mechanism to manage the reactive power in the TSO/DSO connection point.

Proved Benefits

Utilisation of distributed BESS (office and industrial scale) were proven to be efficient and reliable assets to provide ancillary services to the frequency containment reserve market operated by the Finnish TSO. Other demonstrated assets (residential BESS, EV-chargers and residential electricity storage heating loads via AMR meters) had technical and financial limitations yet to be resolved. However, in future these assets could provide active power flexibilities to the TSO.

The demonstrated reactive power market, as a proof of concept, proved a benefit for an Aggregator to utilize the flexibility assets of reactive power in a market-based manner in principle similarly to active power assets. For the DSO and the TSO additional controllable reactive power assets will in the future be needed when the changing of reactive power profiles are expected to continue. A market-based approach could represent an appealing option to strengthen to have more controllable assets in the power system. Technically, the reactive power demonstration was successful. However, when no such market exists at the moment, the creation and maintenance of such a market with all the ICT etc. would need considerable efforts and is not seen economically viable at the moment.

2. KEY MESSAGES FROM EU-SYSFLEX DEMONSTRATORS IN THE DISTRIBUTION SYSTEM

The three distribution system demonstrators of EU-SysFlex have shown that various scarcities arise in different countries and different voltage levels. Within the demonstrators' field test, they have proven that these scarcities can be solved with different flexibility solutions and mechanisms. As the distributions system demonstrators complement each other, they jointly underline the following set of aggregated 13 key messages. The key messages are not only formulated but also evidences based on the results of the three demonstrations are given to prove them.

System operators need to find new solutions to deal with the increasing share of renewable energy resources and the electrification of the heating and mobility sector.

Proof from German Demonstrator

The German Demonstrator's area has a ratio of RES/consumption of 122 % in 2020. This is not merely a single outlier but the peak to a continuous development, as the ratio has been above 100 % since 2017. This leads to a continuously rising need of electricity transmission leading to more and more frequent congestions in transmission and distribution grid. Therefore, new solutions are needed to handle the rising congestion events.

The increase of the share of RES also leads to a shortage of today's redispatch potential from conventional power plants in Germany. If generating units were to produce as traded on the market and without TSOs performing redispatch, many lines would show congestion in the grid (see for example red transmission lines in Figure 2.1).

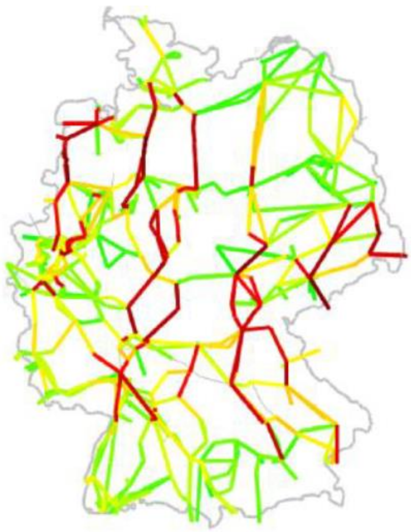


FIGURE 2.1 GERMAN TRANSMISSION GRID BEFORE REDISPATCH (SOURCE: BNETZA, GERMAN REGULATORY AUTHORITY, 2017)

After performing redispatch at transmission level, there are still some lines with more than 100% use of capacity (red bubbles in Figure 2.2) in the situation without any transmission line failure - the (n-0)-case. The transmission system in Germany should be operated according to the (n-1)–criterion, meaning that the line loading should remain under 100% even with any given line experiencing a failure. Including RES connected to the distribution grids in the redispatch process, would increase the redispatch potential and would therefore allow a line loading in the transmission grid to be lower than 100% for the (n-1)-scenario.

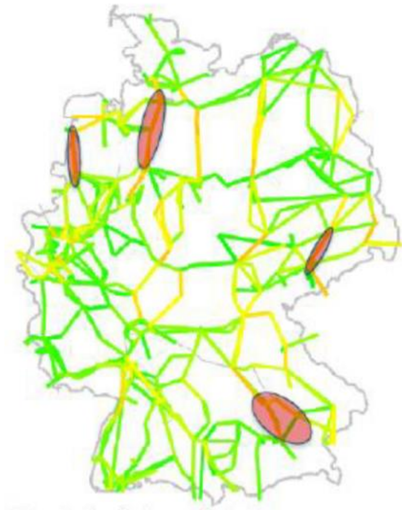


FIGURE 2.2 - GERMAN TRANSMISSION GRID AFTER REDISPATCH (SOURCE: BNETZA, GERMAN REGULATORY AUTHORITY, 2017)

In addition to that, in autumn 2018 a voltage-threatening event happened in the German Demonstrator's area creating voltage violations. The voltage drop that happened on October 24th 2018 can be seen in Figure 2.3. The figure displays 8 hours on the x-axis and the voltage in kV of the EHV grid on the y-axis with the lower limit of acceptable voltage range of 390 kV. The voltage drop could only be stopped due to emergency measures of active power curtailment of 1 GW in the grid of MITNETZ STROM and additional active power in the grid of neighbouring DSOs. It was caused by the large amount of energy transported from north to south and the failure of reactive power support in the transmission grid. Further small voltage drop would have led to a blackout due to the dependency of transported energy, voltage and reactive power need. The occurrence of events like this proves the need for new solutions like innovative voltage control across DSOs' and TSOs' individual borders.

FIGURE 2.3 VOLTAGE PROFILE DURING THE CRITICAL EVENT IN GERMANY

Furthermore, a change in the German law, including significant modifications related to the congestion management process, has recently been passed as NABEG[2] 2.0 These changes require an adaption of the redispatch process. The goal is to ensure highly effective and cost-efficient use of flexibility to solve congestions. Such a

[2] (Netzausbaubeschleunigungsgesetz meaning Grid Expansion Acceleration Act

regulatory development highlights the imminent need of enhancing the usage of available flexibility for congestion management in Germany.

Additionally, discussions with the TSO in the course of the demonstrator prove that they also need new solutions and new sources of flexibility, as conventional plants are being displaced and cannot offer the former amount of flexibility.

Proof from Italian Demonstrator

The distribution networks in Italy are characterized by a high penetration of RES (about 25 GW of RES connected to the distribution network level in Italy, from about 120 GW of total installed electricity production capacity), which can cause voltage violations and overloading of lines and transformers.

In detail, figure 2.4 shows the evolution trend of RES connected to the E-Distribuzione network for the last two years, also offering an estimate for the 2022 horizon-year.

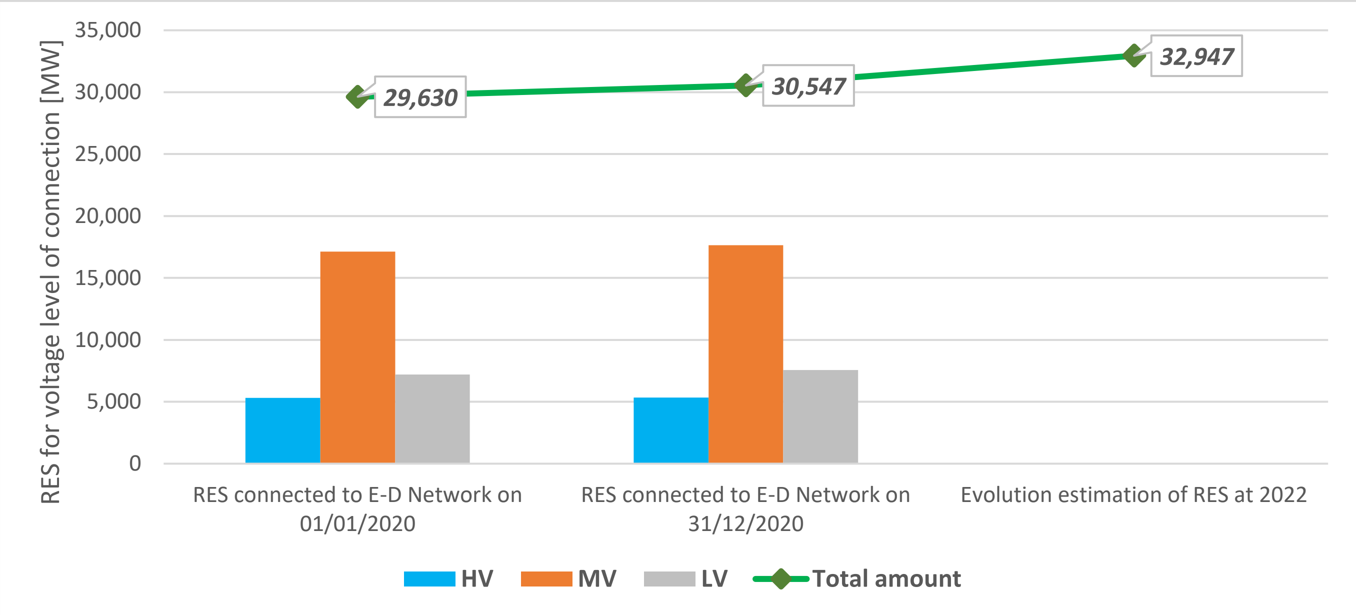


FIGURE 2.4 EVOLUTION OF RES CONNECTED TO E-DISTRIBUZIONE GRID

In this scenario, the DSO must guarantee a high quality of distribution network services, by adopting some actions such as the replacement of lines and transformers; in addition improved and innovative network automation technologies have started to be adopted for the management of the DSO network. Nowadays, the increase of energy generated by RES and, on the other hand, the decrease of generation from traditional plants cause a lack of resources used to regulate frequency and voltage in the transmission network, resulting in a higher probability to have congestions. In this framework, the Italian Authority incentivizes the adoption of smart grid solutions by DSOs in order to improve the operations of distribution networks and also acts to support the management of transmission network, encouraging the aggregation and the access of RES to the ancillary service market. For this reason, the DSO must design and implement new network functionalities, exploiting results from funded projects and experimentation, going beyond the actual regulatory restrictions.

This may allow the DSO to exploit DERs in contingency situations and to guarantee determined levels of continuity of supply and quality of energy.

Proof from Finnish Demonstrator

New technology provides innovative solutions to deal with increasing share of renewable energy in the electricity grid. In the Nord Pool grid, area wind generation is increasing rapidly and old combined heat and power generation is decreasing share of power generation. New technologies such as BESS (battery energy storage system), EV (electric vehicle) charging can provide innovative solutions for grid balancing services. In EU-SysFlex Finnish demonstration, these assets were technically tested to provide ancillary services to the Finnish TSO Fingrid. Technical feasibility of three different size BESS was tested to provide frequency containment reserve for normal operation services to the TSO. Industrial and office scale BESS showed that these assets can provide a reliable and innovative solution for grid balancing. As the transportation sector electrifies the charging of the vehicles provides new possibilities for active power control in the power system. EV-charging points were tested with frequency containment reserve for disturbance operation and the demonstration showed that EV charging control could provide an innovative solution for grid balancing. However, the tested platform and charge points could not meet the strict technical requirements, fast response time, presented by the TSO. Traditionally, electricity storage heating is seen as an attempting flexibility resource. In the EU-SysFlex, these assets were to be operated for mFRR (Manual Frequency Restoration Reserve) where Aggregator activates these flexibilities by the TSO's request via DSO's owned AMR meters. The technical tests revealed that when aiming to simultaneously control a high amount of heating loads it was not possible to fulfil the time limits set by the TSO with the present first generation AMR meters and their management system.

In Finland, reactive power characteristics have drastically changed during the past decade by quickly altering from mainly inductive profiles towards capacitive reactive power. This development is experienced through the whole power system by the TSO (Transmission System Operator) as well as DSOs (Distribution System Operator). Figure 2.5 presents measurement data of the TSO/DSO connection in Helsinki, Finland in September 2019. The red line shows the limit of the reactive power flow. This limit is set by the TSO. If it is exceeded, the reactive power tariff comes into force and this means considerable costs for the DSO. The light red ellipse presents the over flow of reactive power. The DSO lacks controllable reactive power assets. In EU-SysFlex, the new controllable reactive power assets connected to the distribution level, such as inverter-based energy resources were demonstrated to this purpose.

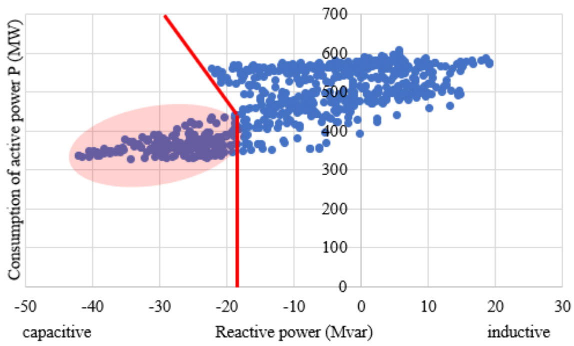


FIGURE 2.5: MEASUREMENT DATA OF TSO/DSO CONNECTION, HELSINKI, FINLAND IN SEPTEMBER 2019. LIGHT RED ELLIPSE INCLUDES THE HOURS OF REACTIVE POWER OVER FLOW FROM THE DSO NETWORK TO THE TSO'S TRANSMISSION NETWORK

The reasons of the considerable changes of reactive power characteristics are the increased cabling of the distribution networks as well as the significant changes of reactive power profiles of consumers. In addition, the costs of reactive power are increasing for utilities. In the TSO/DSO connection points, DSOs are to manage the reactive power flow from/to the transmission system. By this operation, the voltage control on the TSO's transmission network is supported. More controllable reactive power assets are needed. When decentralized production and renewable energy gradually increases, DSOs could have flexibility markets to improve control of the distribution network and at the same time, DSOs could support the operation of the TSO. The DSO markets could operate through the same aggregators that are currently aggregating active power resources to the ancillary markets of the TSO. However, at the same time, there are new controllable reactive power assets connected to the distribution level, such as inverter-based energy resources. The Finnish demonstrator presented a proof-of-concept of a reactive power market utilizing those assets. In the demonstrated market, the developed reactive power forecast at the TSO/DSO interface was applied. Furthermore, new controllable flexible resources (in this paper, Battery Energy Storage System (BESS) and inverters of a photovoltaic (PV) plant) were utilized and their operation by the Aggregator was presented. In EU-SysFlex, a proof-of-concept of the local reactive power market was introduced and tested. However, still no such market exists at the moment. On the other hand, this kind of an approach of a local market is promoted in the EU level.

Today's low observability of the distributed generation plants behavior and the distribution system hinders an efficient integration of renewable energies in system operation. An increased system observability in distribution grids shall be achieved.

Proof from German Demonstrator

The observability of the behaviour of connected assets to predict grid states is very good concerning the transmission and high voltage distribution levels. It is however only rarely the case regarding low and medium voltage grids. This lack of observability limits the possible options and the efficiency of lower voltage control actions for grid operators. The situation could be improved by applying some of the experiences from the high voltage levels.

The tools of the German demonstrator improve the observability in the high voltage distribution grid and partly in the underlying voltage levels. The results show an increase in the amount of possibilities and in the efficiency of flexibility usage. The inefficiencies due to a lack of visibility of flexibility potential are outlined for the next key message.

Proof from Italian Demonstrator

As mentioned in the ARERA consultation paper 361/2020/R/ EEL, regarding the implementation of the TSO-DSO data exchange for the increase of the observability of the resources connected to the distribution network, an advanced observability could guarantee the reduction of risks in terms of security of the national electricity system and a decrease of the provision costs of the resources for the supply of dispatching services. This would lead to an evolution of the distribution network management.

Information about exchanged power from renewable resources makes network state estimation algorithms more accurate. The actual regulatory framework does not allow the direct control of RES. In the Italian Demonstrator, DSO demonstrates that it is capable to increase observability by improving its infrastructure with Smart Grids devices and Forecast functionality. The use of Energy Regulation Interface represents the basis for the definition of the CCI (Central controller interface), which allows to gather useful information from the power plants in order to respond to observability requirements. The Italian Demonstrator sets up an automated coordination process between DSO and TSO by using an IEC 104 protocol simulator, which acts as a substitute in the transmission of some specific signals and measurements between the DSO and the TSO. In addition, the CCI, whose technological features are described in details in Annex O of technical standards CEI 0-16, will allow to monitor and coordinate the operation (point of work) of the different elements of the distributed power plants (regulation and control functionalities). In the Italian Demonstrator, the behavior of the power plants, which are not regulated, is estimated thanks to the Nowcast for Observability, which exploits weather stations.

The increasing complexity of the system requires to test and integrate new assets. It is crucial to foresee a proper remuneration mechanism for these investments in order to reach an advanced smart grid infrastructure.

Proof from German Demonstrator

In today's system operation, RES plants are being curtailed in order to prevent line overloading and voltage violations. This curtailment and the respective compensation costs are considered inefficient, because they pay for a non-delivered energy. The yearly evolution of the curtailment compensation costs for each technology is shown in Figure 2.6.

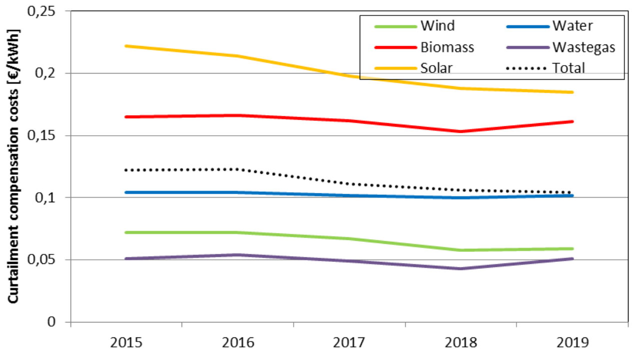


FIGURE 2.6: EVOLUTION OF CURTAILMENT COMPENSATION COSTS

Figure 2.7 shows the evolution of the resulting curtailment costs in the region of 50Hertz, including the German Demonstrator.

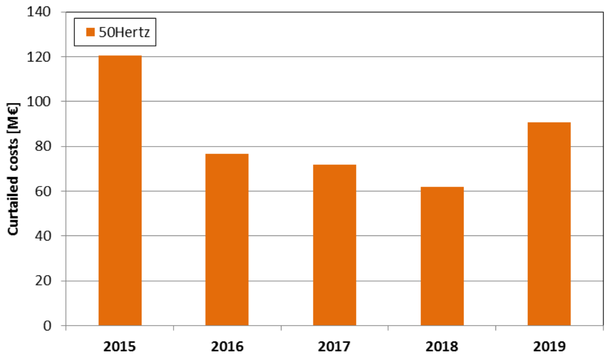


FIGURE 2.7: CURTAILMENT COMPENSATION COSTS FOR TSO 50 HERTZ AND THE DSOS CONNECTED DOWNSTREAM [SOURCE: BUNDESNETZAGENTUR]

The rising curtailment compensation costs give proof of the inefficiency of the current process. The process of the German Demonstrator has successfully increased the observability and therefore the visibility of the available flexibilities. The improvement in the efficiencies is evaluated for the German demonstrator's region (Figure 2.8). An extrapolation on the whole region of 50Hertz is needed for a comparison to the historical numbers.

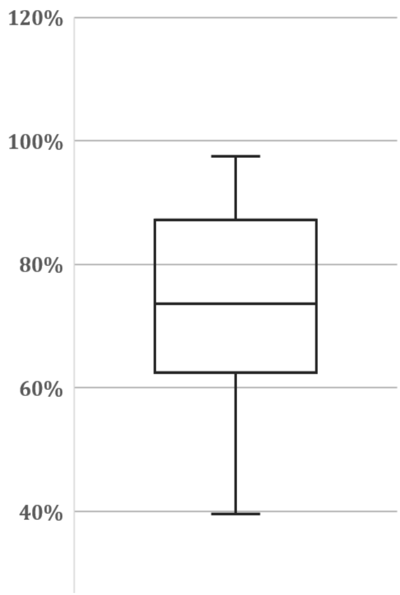


FIGURE 2.8: AMOUNT OF NEEDED FLEXIBILITY WITH GERMAN DEMONSTRATION APPROACH COMPARED TO OLD PROCESS

As shown in Figure 2.8, the introduction of the German demonstration system creates benefits for the whole system, but due to regulation, the remuneration of operating such a system for integrating distributed flexibilities to increase efficiency and reduce compensation costs is not sufficient.

Proof from Italian Demonstrator

Several functionalities can lead the DSO to facilitate the access of the decentralized resources to different ancillary services. Firstly, the storage allows better network operations with peak leveling and can solve congestions and optimize the distribution network in extreme conditions, as in period characterized by a renewable production surplus due to seasonality or mitigate the instantaneous deficit of active power, in case of disconnections of RES. In addition, Italian Demo SCADA functionalities may be part of a more integrated and advanced Distributed Energy Resource Management System (DERMS), able to act on flexibility service providers and aggregators by mean of smart grid devices, integrating market interfaces with existent tools. As a consequence, this innovative approach is able driving the DSO to an improved integration between its connected active and passive customers and distribution network operations.

The DSO acquires lots of measurements and network events thanks to a set of Intelligent Electronic Devices installed in the distribution network. Consequently, the capillarity of the acquired measurements increases and the DSO can actively control assets, implement automated procedures for fault selection, perform network state estimation and prevent network outages. In order to pursue this objective, the DSO must integrate as much as possible the controllable resources and new network assets to deal with several system operation scenarios.

In order to meet both TSO and DSO network needs, Storages will play a key role to increase RES participation to active power related ancillary services. Similarly, STATCOM will be crucial to perform Reactive Power compensation and Voltage Support, in order to maintain a high quality voltage profile in each node of the distribution network, with high penetration of DERs, long MV feeders and distribution Hubs.

System operators need to harness new opportunities arising from decentralized flexibility resources to increase the efficiency of a secure system operation.

Proof from German Demonstrator

In the area of the German demonstrator a steady decrease in the redispatched energy, especially between 2017 and 2018 can be observed. This evolution of the yearly redispatched energy by the TSO 50 Hertz is illustrated in Figure 2.9.

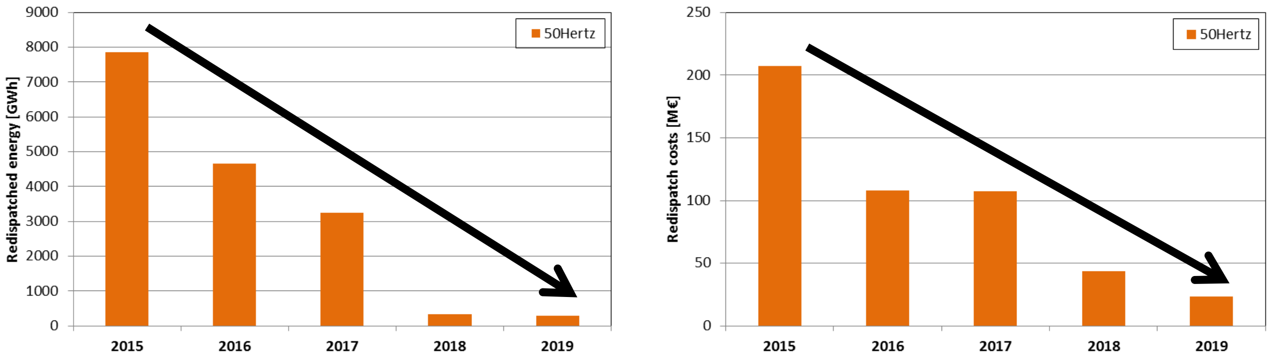


FIGURE 2.9: REDISPATCH AT TSO 50 HERTZ, (LEFT) ENERGY, (RIGHT) COSTS [SOURCE: BUNDESNETZAGENTUR]

From the historic values alone, it can not yet be concluded that the reduction of redispatched energy is a flexibility scaricity of the TSO. But combined with evaluation of the curtailed energy in the region the scarcity becomes visible, since **if there was curtailment, it is because the redispatch capacity was insufficient**. Figure 2.10 shows the evolution of curtailed energy in the same region of 50 Hertz, including all the curtailed energy, both from the TSO and the downstream DSOs. The redispatch and curtailment data are being combined for comparative purposes. Although the need for redispatch and curtailment is plummeting, curtailment is still needed. Therefore the scarcity of resources in schedule-based process as redispatch is increasing.

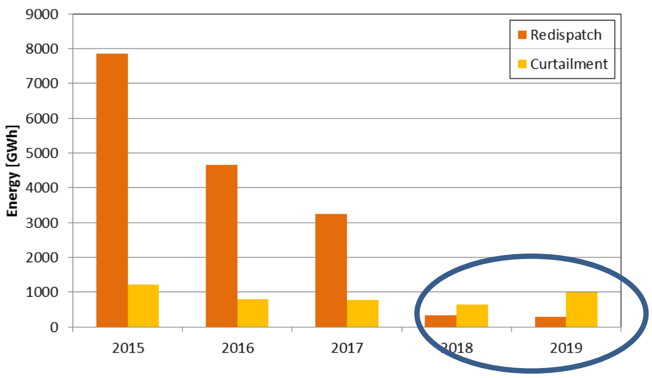


FIGURE 2.10: REDISPATCHED AND CURTAILED ENERGY FOR TSO 50 HERTZ & THE DSOS CONNECTED DOWNSTREAM [SOURCE: BUNDESNETZAGENTUR]

For 2019, it can be seen in Figure 2.10 that for the first time redispatch measures decrease and curtailment is increasing. Concluding, the TSO has scarcity of redispatch potential to prevent grid congestion and therefore curtailment as emergency measure is used. Compared to that, the RES connected to the 110 kV distribution grid have available flexibility that they can offer. The presence of these available active and reactive power flexibilities for a schedule-based process is shown for an exemplary distribution grid, with high amount of installed wind power plants, in the demo region in Figure 2.11. This proves that there are flexibility opportunities in the distribution grid, which can be harnessed by the TSO in a scheduled-based process as redispatch and not only for emergency measures as curtailment.

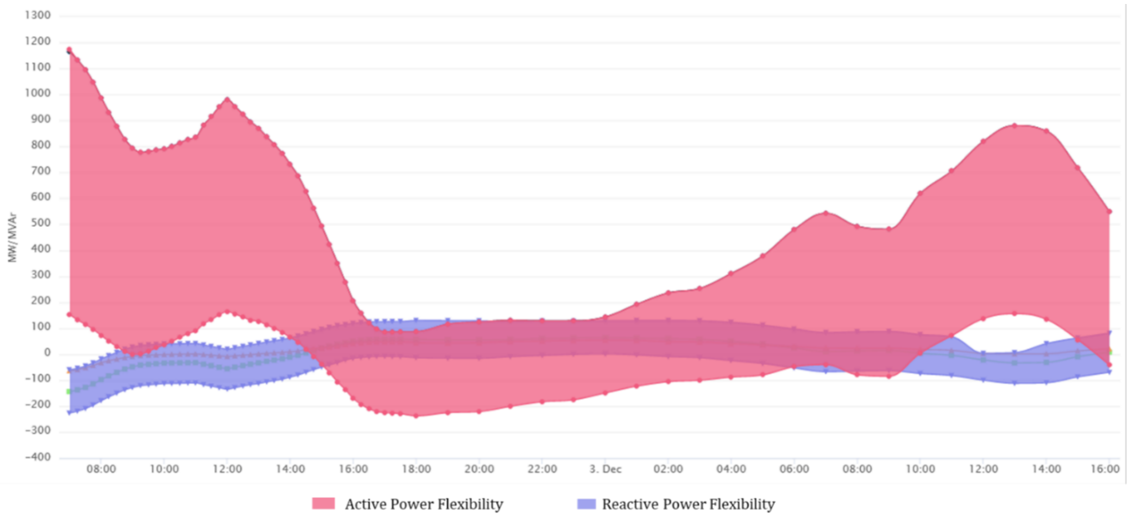


FIGURE 2.11 ACTIVE (PINK) AND REACTIVE (PURPLE) POWER FLEXIBILITIES FOR AN EXEMPLARY GRID GROUP

Proof from Italian Demonstrator

The demonstration offers new opportunities to exploit experimentation results for new scenarios in the network services, in particular for the creation of markets for non-frequency ancillary services at the distribution level in accordance with EU directive 944/19.

Comprehensive simulation tests have been carried to verify and validate the new functionalities introduced in the optimization algorithm. One of the objectives of the off-line simulations was to analyze and quantify the maximum range of reactive power flexibility the demonstrator network can provide and how it is impacted by network constraints. These tests considered different flexibility shares, based on the existing flexible resources connected to the demonstrator network, divided in five case scenarios, from the lowest to the highest flexible share (Case 1 to Case 5).

The maximum theoretical aggregated reactive power capability during a reference day (Figure 2.12), is estimated relaxing the network constraints.

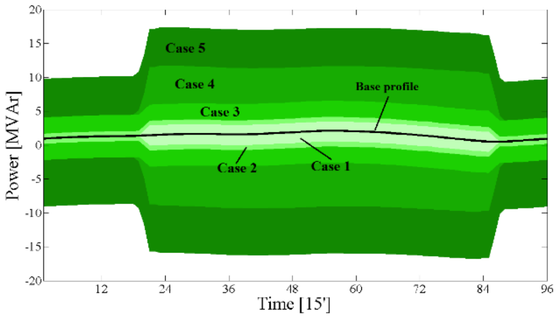


FIGURE 2.12 PICTORIAL COMPARISON OF THEORETICAL REACTIVE POWER CAPABILITY AREAS

The results show that the flexibility share from different types of flexible resources gives plenty of reactive power regulation during the whole day. Specifically the contribution from PV plants is significant during the daylight hours while the flexibility share from conventional power plants, from FACTS devices and Battery Storage is essential for allowing reactive power modulation at night.

In a second simulation, the network constraints were considered in the optimization 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 without relying on optimization and/or OLTC operations. An excerpt of the results achieved from this second set of simulation is shown in Figure 2.13

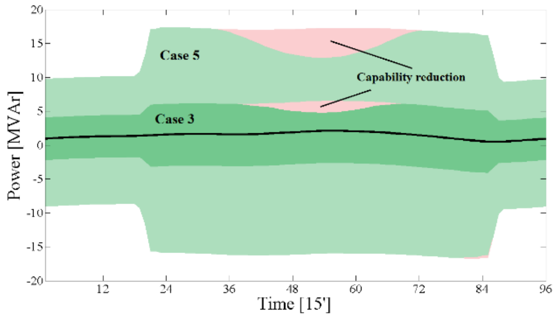


FIGURE 2.13 - EXAMPLE OF REACTIVE POWER CAPABILITY REDUCTION

The magnitude of the capability reduction is proportional to the total theoretical area, since the reactive power capability increases steadily as flexibility share increases. Furthermore, it is clearly visible that the reduction is limited to the central part of the day, so the PV production represents the strongest constraint for reactive power capability exploitation.

One of the main assumptions behind the first two preliminary tests presented so far is to keep the tap voltage of Primary Substation transformers fixed at a reference set-point which allows losses minimization, as in standard network operations. A third set of simulation tests was arranged in order to investigate how OLTC management may influence the reactive power capability area.

In these tests, the optimization tool was run considering, time by time, wider tap shifting ranges; starting from zero, the number of tap shifts the OLTCs were allowed to do around zero are increased, one step at a time.

Figure 2.14 shows an excerpt of the results from the third set of tests: the lighter color shade corresponds to a +/-1 tap shifting range while the darker ones corresponds to progressive widened ranges (+/-2, +/-3, and so on).

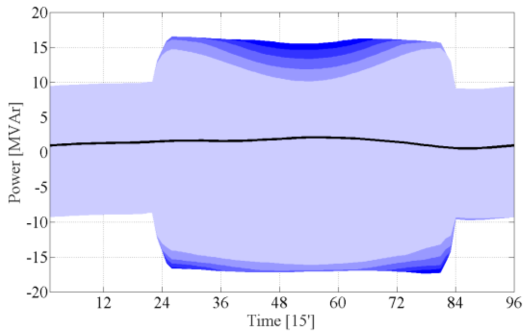


FIGURE 2.14 EXAMPLE OF REACTIVE POWER CAPABILITY AREA VERSUS OLTC TAP SHIFTING RANGE

It can be noticed that the +/-1 tap shifting range is suitable for exploiting the most of the capability area, while wider ranges are needed only for maintaining the full capability area in specific periods of the day.

Proof from Finnish Demonstrator

The Finnish demonstration showed that decentralized flexibility resources are efficient and secure for use in grid stabilisation. The demonstration reached important development steps where decentralized assets an industrial-sized and an office-scale battery were operated in the TSO ancillary markets. In addition, remote control and control logics were successfully developed and tested for the PV power plant, customer-owned batteries and EV-charging points.

In Finland, the reactive power values show a strongly declining long-term trend towards more to the capacitive characteristics (Figure 2.15). This development together with the increasing cost of reactive power caused the TSO and DSOs to react and develop solutions of reactive power control. The Finnish demonstrator piloted a proof-of-concept of a local reactive power market to have more controllable reactive power assets for the DSO and simultaneously for the TSO. When decentralized production and renewable energy gradually increases, the new types of assets were so far untapped reactive power assets of various inverter-based energy resources. The proof-of-concept market operates through the same aggregators that are currently aggregating active power resources to the ancillary markets of the TSO. In EU-SysFlex, the reactive power market approach has been demonstrated as a technical proof of concept. For the DSO, the aim is to operate successfully in the TSO/DSO connection point and in the PQ window to avoid or minimize the penalty costs caused by excessive reactive power flow. For the aggregator, the objective is to gain profit from the market operations, and divide the income together with their customers in question.

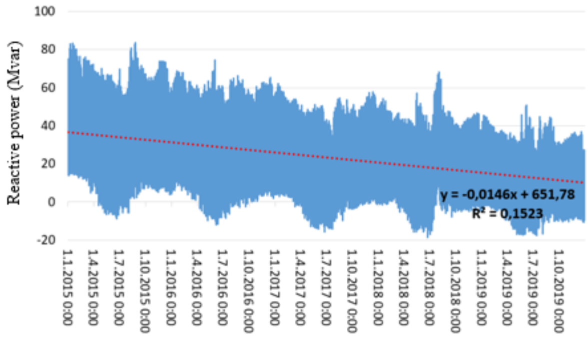


FIGURE 2.15: THE TREND OF RECTIVE POWER IN HELSINKI, FINLAND PRESENTING REACTIVE POWER VALUES ON THE MEDIUM VOLTAGE SIDE OF THE 110 KV/MV TRANSFORMERS

The role of the DSO is evolving more and more to an active system operator in all voltage levels. The DSO shall therefore be allowed to use all flexibility technologies connected to its system to fulfil its responsibilities.

Proof from German Demonstrator

The proof from first key message and the proven availability as described above underline the evolving role of the DSO. Already today an active system operator role is implemented by European regulation, namely in the Electricity directive 2019/944 acknowledging this evolution. It is absolutely necessary to guarantee this also in the future.

Proof from Italian Demonstrator

The DSO needs to exploit DERs not only for normal network operations, like voltage variations, but also to deal with contingencies, interruptions or phenomena due to extreme weather conditions, to guarantee continuity of supply and quality of energy. Consequently, this demo allows the study of new scenarios in which DERs are exploited to solve the abovementioned problems, enabling the concept of resilient network.

The DSO is called to operate the distribution network as a System Operator, analyzing network constraints and managing energy fluxes, performing congestion management, balancing and voltage regulation in order to guarantee continuity and quality of service for all the connected customers.

In order to achieve this objective, the DSO must optimize the distribution network both for its own scopes and to satisfy the requests coming from the TSO, exploiting new SCADA functionalities and an advanced Smart Grids infrastructure.

The DSO needs to be involved in operational planning and in the procurement of congestion management and voltage control services, given that most of the flexibility resources are connected to the distribution grid. Therefore, an increased DSO/TSO coordination is needed.

Proof from German Demonstrator

Discussions with the German TSO during the course of the project prove the common need and goal to jointly use and harness distributed flexibilities connected to the distribution system. It is seen that without information exchange, the use of flexible resources connected to the distribution network by the TSO can harm the stability of the distribution grid. Therefore, it is imperative to improve the information exchanges between the DSO and TSO. Furthermore, the discussions prove an imminent need for the implementation of an efficient coordination process between the TSO and DSO in order to better use the available flexible resources and to avoid jeopardising the distribution systems operation.

The congestion management process in Germany as well as the voltage control when the demo was set up[3] involve the DSO only at a very late stage. The process for congestion management today regarding solving congestion in the transmission grid is visualized in Figure 2.16.

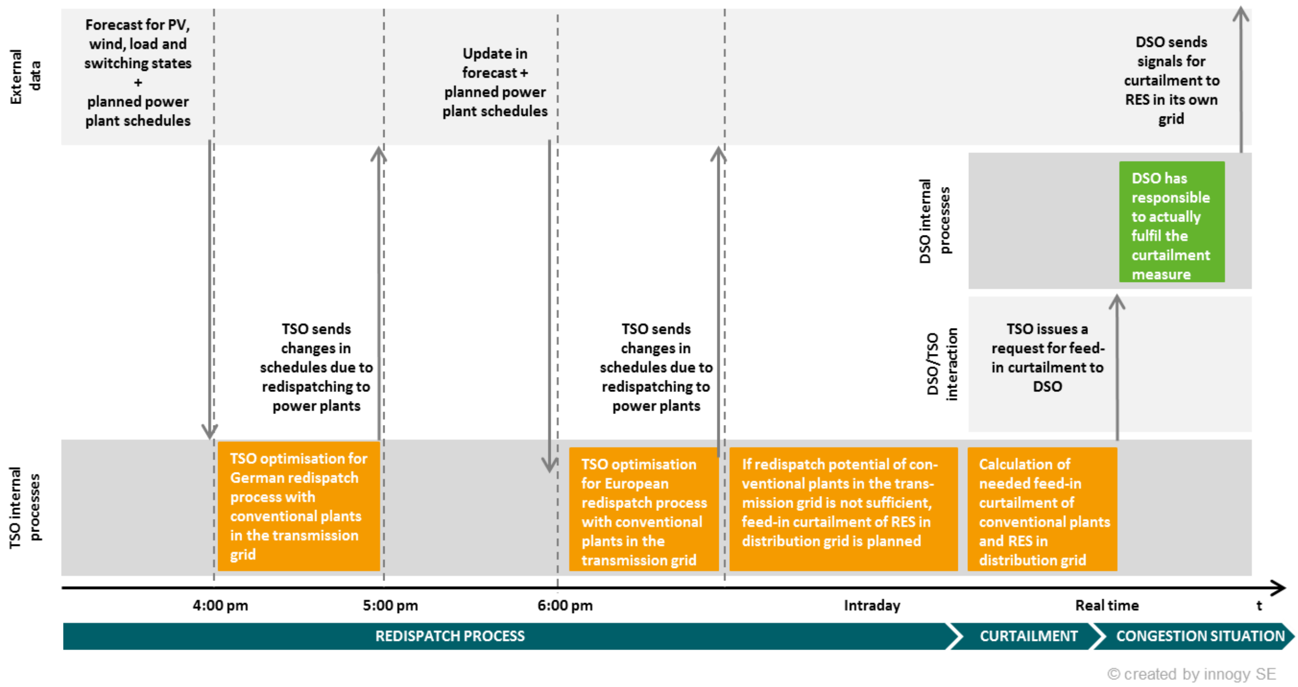


FIGURE 2.16 PROCESS OF THE GERMAN CONGESTION MANAGEMENT TODAY

The established process within the German Demonstrator for including RES from the distribution grid and therefore the DSO in congestion management ensures an early coordination. The main difference to the status quo process is the integration of the DSO in the whole process and not only in emergency measures close to real time. This process enabling the provision of active power from flexibilities in the distribution grid to the TSO for relieving congestion in the transmission grid is defined as displayed in Figure 2.17 and continued for an iterative intraday process for active power flexibilities.

[3] A change in the German law took place in October 2021, including significant modifications related to the congestion management process: NABEG 2.0 (Netzausbaubeschleunigungsgesetz or Grid Expansion Acceleration Act). These changes have required an adaption of the redispatch process. The goal is to ensure the use of the most effective and most cost-efficient flexibility to solve congestions. Such a process was already being tested in the German demonstrator of EU-SysFlex prior to the publication of the law.

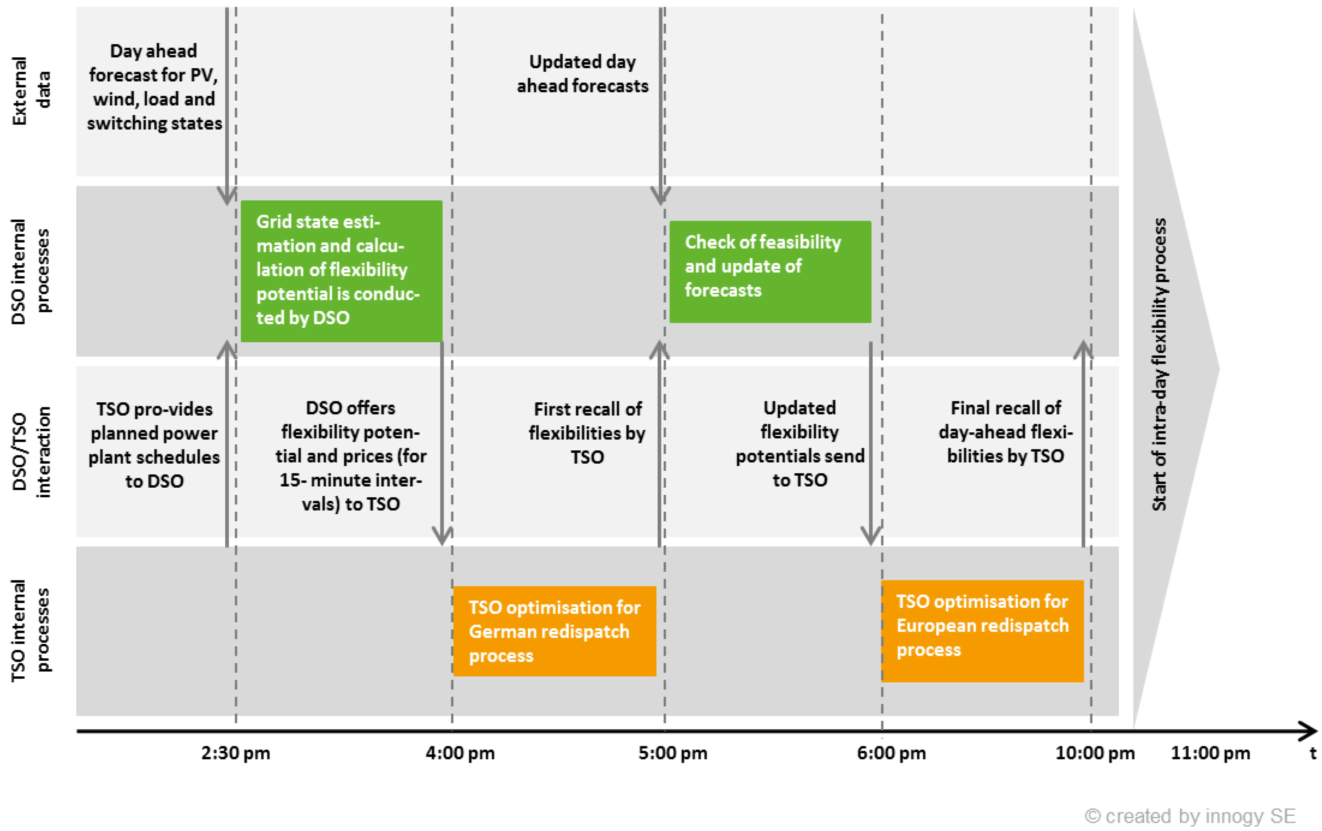


FIGURE 2.17 DAY-AHEAD PROCESS FOR ACTIVE POWER FLEXIBILITIES

The involvement of the DSOs in the reactive power management processes is analogously designed in the German Demonstrator.

Proof from Italian Demonstrator

The Italian TSO Terna prescribes all the activities regarding the remote control and measurements acquisition for the operation of all the plants connected to the National Transmission Network, which includes amongst others all the primary substations of the connected DSOs [Annex A6 of Network Code].

In particular, the TSO requires that the DSO sends respectively:

- the real time positions of all the circuit breakers of the HV/MV Transformers;
- the real time measurements of Active and Reactive Power at the HV/MV Transformers.

The DSO SCADA is designed to provide all this information to the TSO SCADA according to the System Operation Guidelines.

Within the project objectives, the DSO may provide an aggregated information of network capability at its interface with the TSO, which in the Italian demonstration is represented exactly by the HV/MV Primary Substation. The DSO needs to perform congestion management and voltage regulation on its grid, and could also facilitate and support the provision of some network services to the TSO, by decentralized resources.

In this new scenario, the TSO has to solve transmission network constraints and needs to know the amount of energy produced by plants connected to the distribution network. Therefore, it is necessary to review and update the coordination/interaction processes between these two actors.

Therefore, the Italian Demo tests the EUSysFlex solution exploiting an already existing SCADA architecture, adding the fields related to the reactive power capability and the TSO aggregated set point request of Voltage and Reactive Power. As an example, Figure 2.18 shows the Reactive Power Capability $Q_{min}÷Q_{max}$ and the reactive power set point for voltage regulation.

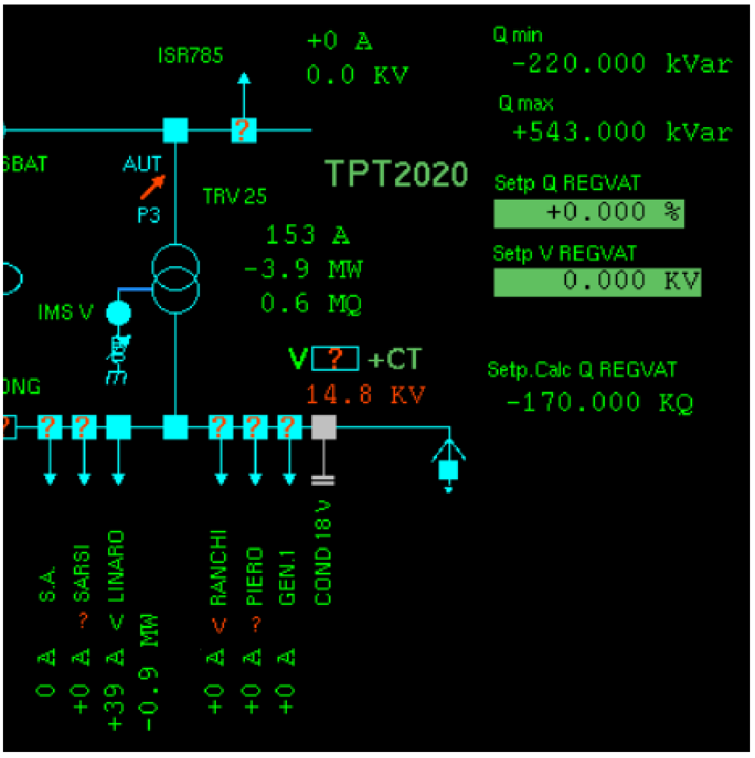


FIGURE 2.18 - EXCHANGED DATA FROM DSO SCADA TO TSO SCADA.

In particular, considering that the Italian TSO did not join EU-SysFlex project, E-distribuzione simulated the data exchange between DSO and TSO SCADAs.

The Italian Demonstrator has tested an automated coordination process between DSO and TSO by using an IEC 104 protocol simulator, which acts as a substitute in the transmission of some specific signals and measurements between the DSO and the TSO.

For an efficient and effective DSO/TSO coordination, the process for flexibility selection and activation shall be as far as possible automated and based on the following principles:

- ***Every system operator is responsible for its own grid.***
- ***Every system operator predicts the available flexibility potential in its own grid.***
- ***System operators from connected grids are being informed about available flexibility potential.***
- ***Flexibility selection and activation for congestion management and voltage control is carried out by the system operator where the flexibility is connected to.***
- ***Both TSO and DSO needs and constraints are taken into account.***

In all three demonstrator we have proven, that these principles for flexibility selection work efficiently. Figure 2.19 illustrates the flexibility selection process for active power within the three demonstrators.

In Germany, the law (§1 EnWG) states that each system operator is responsibility for the operation of its own grid. A decentralized optimization process for flexibility selection follows that paradigm. In the **German Demonstrator**, the DER send their schedule and flexibility offers to the DSO, which selects flexibilities for its own use and aggregates the potential for the TSO. The TSO then selects aggregated flexibilities for the use on its own grid. The DSO verifies the feasibility of the TSO's requests, disaggregates it and sends the signal to the DER aggregator, which adapts the active power of its asset. Active power in the German Demonstrator is used mostly for congestion management and only in very few cases for voltage control.

In the **Italian Demonstrator**, active power is used, only in simulated environment, for congestion management for the TSO and DSO and for frequency control for the TSO. The flexibility is offered by the DER to the DSO, which takes into account the forecasted grid situation, and carries out an optimization to determine which bids can be transmitted to the TSO without causing local congestions and aggregate them. The TSO selects the appropriate aggregated flexibilities after having determined its active power demand and sends this selection to the DSO for disaggregation. The DSO selects the singular DER for flexibility provision so that the units can adapt their active power. It must be noted that the processes of bid optimization, aggregation, and disaggregation are carried out by the DSO only for the purposes of the demonstrator. In the future, that role would be taken by another actor, the market operator for distribution grid.

The **Finnish Demonstrator** focuses on the delivery of frequency products for the TSO. Since the grid is not congested, the flexibility is directly offered to the TSO, which undertakes a ranking of bids. In case of FCR-N (Frequency Containment Reserve for Normal Operation) products, flexibilities detect frequency deviations autonomously so that no external activation signal by the TSO is needed. For that reason, bids are cleared day-ahead on a market platform operated by the TSO based on its demand for FCR-N. Frequency containment reserves are used for the constant control of frequency. For mFRR (Manual Frequency Restoration Reserve), flexibilities are activated by the TSO's request after having undertaken a bid ranking. The TSO sends the information of accepted bids to the aggregator and the aggregator sends an activation request to the asset. The objective of frequency restoration reserves is to return the frequency to its normal range, 49.9-50.1 Hz.

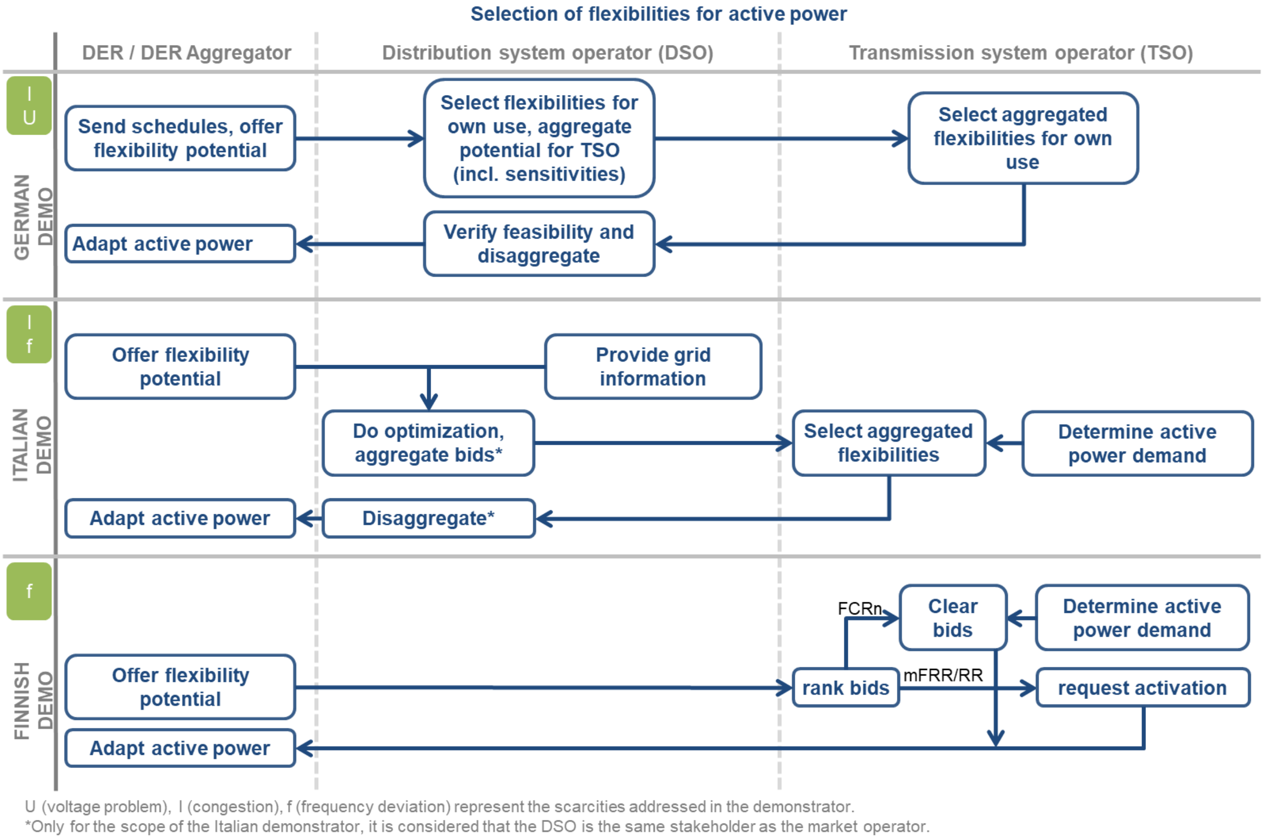


FIGURE 2.19: SELECTION OF FLEXIBILITIES FOR ACTIVE POWER IN THE THREE DEMONSTRATIONS

Decentralized optimization approaches based on the optimization principle "local before regional" shall be applied for flexibility selection as they are highly resilient, efficient and secure.

Proof from German Demonstrator

The decentralized optimization approach following the optimization principle "local before regional" implemented by the German demonstrator has proven to be highly resilient, efficient and secure. It considers the specifics of the different voltage level requirements, creates synergies avoiding conflicts across the different voltage levels and reduces the complexity with regard to data exchange and data processing.

Furthermore, the decentralized optimization approach increases the resilience, since the optimization of each system is carried out by each respective system operator and data exchange can be executed with as much as possible aggregated data. The decentralised approach ensures stronger resiliency because, if one calculation fails, others are still able to end successfully. The impact on the overall system optimization is thus less important than if the centralized algorithm had failed to produce results or similar than if it had mathematically split the optimization problem into smaller sub-optimizations.

Additionally, the decentralized optimization approach in the German demonstrator reduces the data amount needed for exchange. A centralised storage of information would come with a higher risk of distortion during the data transfer and storage. The decentralized approach, in contrast, minimizes the data exchanged and has advantages because not all data is stored in the same place. In the case of a centralized data storage, the various system operators would still have to keep additional, redundant, local storages, as recommended in . ISO 27 001.

For the decentralized approach, coordination is imperative to ensure the efficiency exchange of the nessecary information with the involved stakeholders. As the the German demonstration has proven, the use of equivalent network models to represent missing grid data of others SO grids lead to similar results as if using comprehensive grid data.

Overall, the approach also allocates the responsibility for bid selection and costs to the same actor by clearly assigning the responsibility bottom-up. This is supporting the requirements in the European Energy Directive 2019/944 to keep the own system secure and reliable.

A market based approach for flexibility usage should be applied unless low liquidity and strategic gaming prevents it.

Proof from Finnish Demonstrator

The Finnish TSO has various market places to effectively operate the power systems. However, now with increasing amount of RES connected to the distribution network, new flexibilities area needed. The Finnish demonstrator focused on market-based integration of flexible assets to the TSO ancillary services. The innovative aspect was to integrate and aggregate small, so far untapped flexible assets connected to the distribution network. The Finnish TSO operates frequency contaminant reserve (FCR) markets for normal (N) and disturbance (D) operation. Flexibility services are bought from the market with yearly and hourly contracts. When the TSO purchases flexibility for every hour first the yearly bids are used and if not enough flexibility is provided the rest is purchased from the hourly market. The price for the yearly market is fixed throughout the year whereas the hourly market price varies. The market price for the hourly market for one hour is the highest accepted bid price and all bids accepted are paid with this price.

Battery energy storages (BESS) are a novel and an efficient way to balance the grid frequency in normal operation. However, BESS have limited energy capacity and might either deplete or fully charge during operation if the grid frequency is unfavourable.

EV charging can be used as a resource group to participate in FCR-D market if the EV chargers and backend systems meet the requirements for participating in the market. In the Finnish demonstration, it was found that the used EV charging control platform could not meet the rather fast response time requirement to participate in the FCR-D market.

Electricity storage heating load control via the present first-generation AMR meters and their management system faced issues with the fast response requirements.

A market-based approach is seen to attract suitable flexibility service providers and lower the procurement costs for flexibility and frequency contaminant services.

The Finnish Demonstrator has proven that market based approaches should be applied. In case of low liquidity and high risks of strategic gaming, other options have to be applied. These market options have been evaluated in the EU-SysFlex work about market design coming to the conclusion that a market-based should be the preferred solution, if the necessary conditions are in place to allow for the introduction of a market. Such conditions include sufficient competition/liquidity, transparency and clear market rules, limited strategic behaviour such as increase/decrease gaming.

Forecasting, optimization, control logics as well as reliable communication systems are needed in order to enable the utilization of assets in the flexibility markets.

Figure 2.20 depicts the relationships between the different tools that are used to create the innovative systems of the three demonstrators and their application to fulfil the demonstrators' use cases. As seen in the figure, three groups of tools, namely Forecast, Communication and Optimisation, are needed for the physical demonstration field tests. Furthermore, grid simulations were used to test the functionalities prior to the field tests. It has been proved that in all three demonstrators the integrational use of the tools has enabled to realize the use cases and objectives.

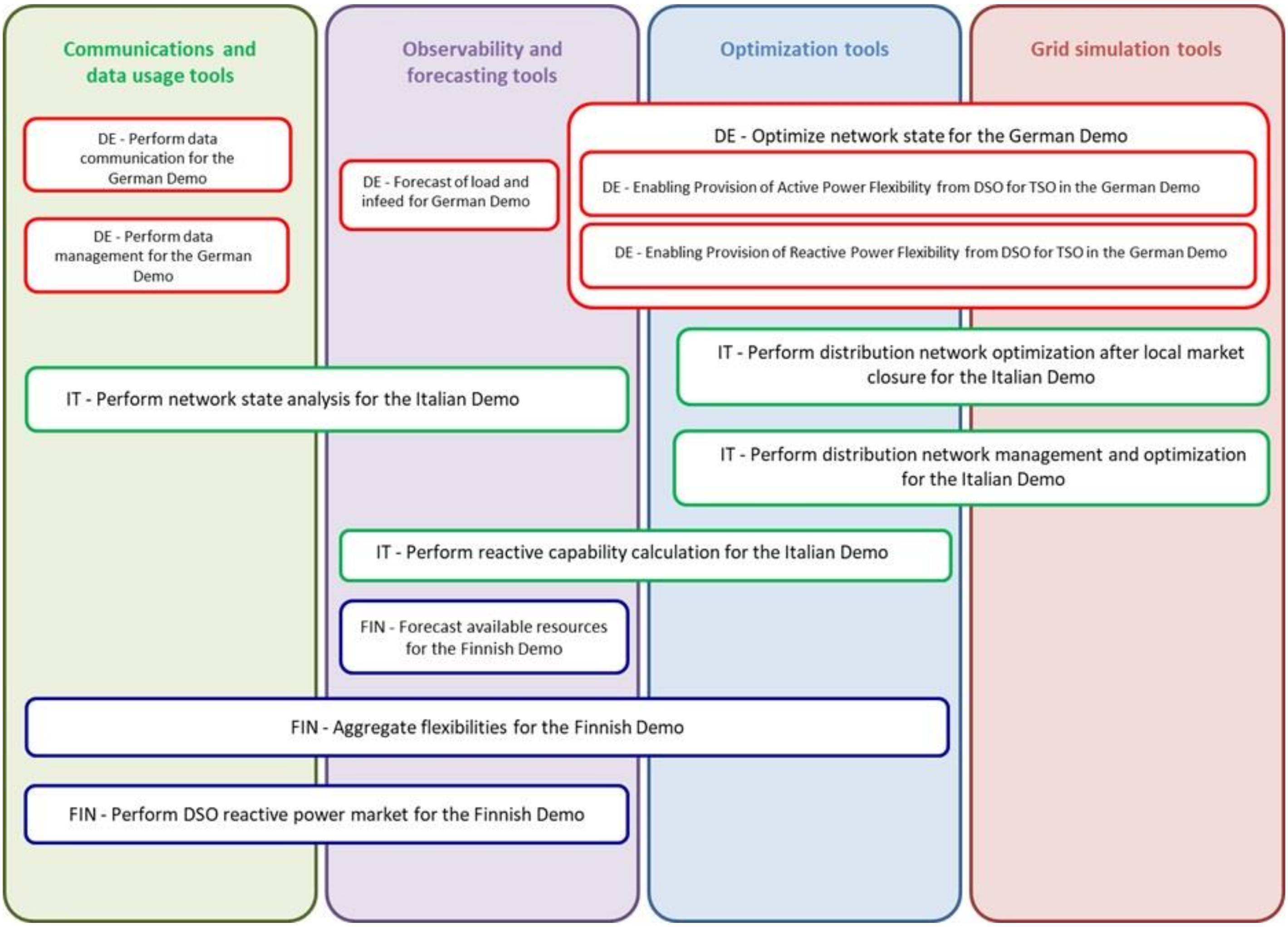


FIGURE 2.20: RELATIONS AND DEPENDENCIES BETWEEN THE FOUR SUBJECTS AND TOOLS

Proof from the German Demonstrator

In the German Demonstrator, the forecasting tool is needed to have reliable input data to start grid state estimation for the future. Without reliable input, the needs for and the available potential for flexibility cannot be calculated reliably. The improvement of forecasting in the German Demonstrator is shown in Figure 2.21.

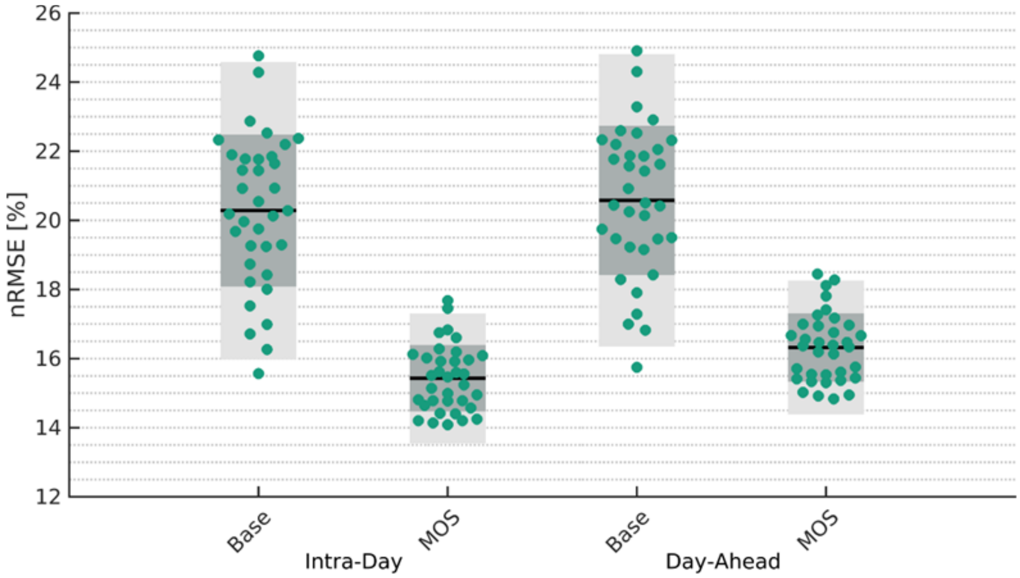


FIGURE 2.21 IMPROVEMENT OF FORECASTING OF PV PARKS IN GERMAN DEMONSTRATOR
THE NRMSE OF THE SINGLE PARKS CAN BE SEEN TOGETHER WITH THE BOX-PLOTS IN THE BACKGROUND. ON THE LEFT SIDE THE RESULTS FOR THE INTRA-DAY FORECASTS ARE SHOWN AND ON THE RIGHT THE DAY-AHEAD FORECASTS.

The optimization algorithms are needed, in the form of intelligent and innovative algorithms, to support decision making for flexibility usage. The architecture of the tool communication is built up with micro-services to ensure adaptability for future needs. Each of these services can be adapted independently and adding a needed service is easily possible. This modular approach of the tool architecture is embedded in a modular environment of the grid control centre of the DSO. The optimization results are then turned into control signals connecting the results to the field assets via the grid control centre communication infrastructure. Communication tools are needed to enable an efficient data exchange and interaction between the different systems and stakeholders (see coordination processes of the German demonstrator). The German demonstrator has proved efficient operation of all tools in the integrated field test set-up.

Proof from the Italian Demonstrator

In the Italian Demonstrator, the generation forecast of loads and generations are used by SCADA in order to trigger the state estimation and the optimization algorithms.

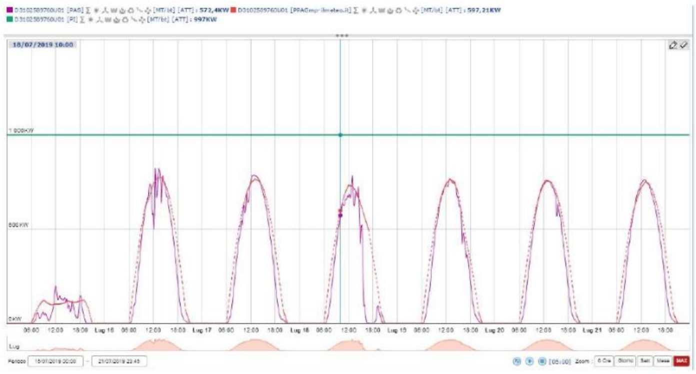


FIGURE 2.22 DIAGRAM OF PV GENERATION FORECAST

The forecast tool provides the forecasted information of generators, considering the measurements of installed power (PI) and the generated active power (PAG) of each plant, taking into account the primary source, even if, for pure producers, it is possible to consider the exchanged active power (PAS); furthermore, the weather variables (including irradiation, environmental temperature and wind speed) are considered. The forecast based on historical data is usually performed for the passive loads.

Figure 2.23 shows a report from the used forecast tool, in which the forecast and the real production during a week in July 2019 are compared. By performing this ex post analysis, it is possible to observe similarities and differences between PAG and PAS profiles.

The optimization process is needed to exploit power flexibilities avoiding network violations: in the Italian Demonstrator the optimization tool performs the necessary coordination between the resources and the distribution network, facilitating reactive power flexibility provision from distributed resources to the TSO. For this purpose, optimization and flexibility calculation routines can identify suitable and reliable set-points, maximizing the share of flexibility between all the participating resources; in this way more resources can be included in the flexibility provision and the total effort can be distributed between them.

Proof from Finnish Demonstrator

The Finnish TSO has various market places to effectively operate the power systems. However, now with increasing amount of RES connected to the distribution network, new flexibilities area needed. The Finnish demonstrator focused on market-based integration of flexible assets to the TSO ancillary services. The innovative aspect was to integrate and aggregate small, so far untapped flexible assets connected to the distribution network. In order to enable the operation of small assets in the flexibility markets, forecasting and optimization, control logics as well as reliable communication systems are critical parts of the successful market-based business operations. In the demonstration, forecasting and optimization tools have been developed specifically for each asset type of the demonstration. The tools of an aggregator aim to 1) forecast the availability of assets to operate in the TSO ancillary markets 2) define the optimal bidding sizes and times 3) define the available potential in the current scenario and in a future scenario (e.g. with more EV chargers). One forecasting tool has also been created for the use of the DSO during the reactive power market demonstration period to determine the need of additional reactive power compensation from the demonstrated market.

Forecasting, optimization, control logics and reliable communication are the key elements of successful business opportunities and operations. In addition to a reliable communication, a fast communication for frequency containment reserves is vital if assets are controlled from a cloud platform and not locally. In the Finnish demonstration, these forecasting, optimization, control logics and communications were developed within the distributed assets, the aggregator’s energy platform and TSO’s market places and in addition, one forecast for the DSO’s needs.

To unlock the potential of new and technically feasible solutions, the modification of the regulatory or market framework is required to eliminate existing barriers. This is only possible with the support of policy makers, regulators and in cooperation with flexibility service providers and prosumers.

Proof from the German Demonstrator

In the current regulation, resources with a limited flexibility, such as demand response, are not considered as flexible for congestion management. To consider these would enlarge the flexibility potential especially in the distribution grid.

In addition, the PQ-Maps tool of the demonstrator shows that the efficiency of the coordination of congestion management between TSO and DSO could be improved by reducing the data exchanges and integrating the interdependencies between active and reactive power. Today's regulation requires the detailed price information for activated resources in this coordination process. Therefore, the aggregated approach of the PQ-Maps could be used in operation only after the responsibility of cost-efficient activation is shifted from the flexibility demanding SO to the flexibility providing SO. It should be mentioned that the redispatch process (schedule-based congestion management) integrates the balancing and therefore this needed change of regulation needs to consider more than the activation of congestion management flexibilities to boost efficiency.

Proof from Italian Demonstrator

In the Italian Demonstrator, where all the Active Power related services are simulated, a good opportunity to increase RES share is represented also by the introduction in network operation of the storage, which, according to the current regulatory instructions, as a DSO-owned asset cannot participate to the centralized transmission ancillary services (mFRR/RR market). Indeed, currently the Italian regulatory framework does not contemplate a local flexibility market accessible for the resources connected to the distribution network neither a remuneration mechanism for reactive power modulation. Therefore, BESS can be used by the DSO to ensure a secure and reliable operation of the distribution system.

Results and observations from the Italian Demonstrator should contribute to drive the elaboration of new network codes (like Flexibility or Interoperability) or the changes and improvement to the existing ones (like SO GL). All these codes or acts are able to define the general rules, in compliance with the technologies implemented or implementable, with the maximum effectiveness.

In this framework, the Italian Demo allows to demonstrate the possibility to implement some of the indications contained in the SOGL regulations, in terms of data exchange between TSO and DSO, finalized to a significant improvement in the System Operators coordination, also making use of the so-called "Significant Grid Users".

The data management principle "data thrift" is essential and at the same time was proven to be feasible and effective if based on three principles:

1) grid data always stays in the sphere of the respective system operator.

2) grid impact analysis remains the responsibility of the respective system operator.

3) data exchange is aggregated as much as possible to reduce complexity.

ISO 27001 stipulates data thrift as principle for data exchange processes.

Proof from the German Demonstrator

As mentioned in other key messages, the German demonstrator has proven the feasibility of equivalent network models as substitute for comprehensive grid data. These equivalent network models are based on historic data of the grid they represent therefore enhancement of cybersecurity is independent from operational timing requirements. Additionally, such approach reduces the amount of data exchanged and it not only supports data thrift but is also in line with the responsibility of each SO to ensure a secure and reliable grid operation. For further improvement, as stated before, the regulation should focus on boosting the efficiency of coordination processes in adopting the three data thrift principles more by assigning a consequent share of responsibility to each SO.

Proof from the Italian Demonstrator

As already mentioned in the key message n.5, the DSO, as a System Operator, must ooptimize the distribution network, avoiding congestions and solving constraints violations, by managing private resources and its own assets in order to follow the agreed profile at HV/MV Substation, resulting only from a continuous and enhanced data exchange between TSO-DSO.

Overall, the distribution system demonstrators prove how flexibilities in the distribution grid can be used efficiently to meet the requirements of both DSOs and TSOs.

Each demonstrator has proven that the flexibilities solve different kind of scarcities. For example in the German demonstrator, all flexibilities are used for solving both congestion due to line loadings and voltage violations. In contrast to that, in the Finnish demonstrator, for example, the inverters of a PV power plant are used to solve voltage violations by offering reactive power only and the residential heating loads and electric storages are used to solve frequency deviations by offering active power.

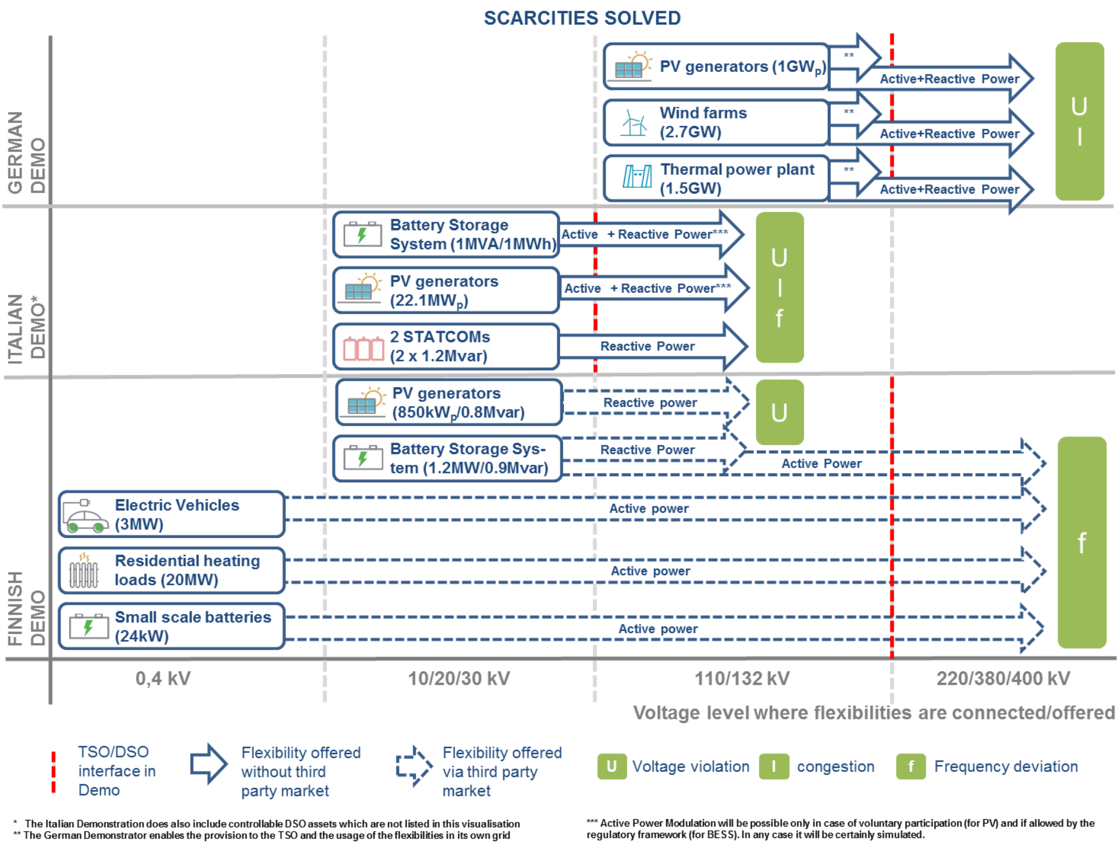


FIGURE 2.23 SCARCITIES SOLVED BY THE FLEXIBILITIES IN THE THREE DEMONSTRATIONS

Proof from German Demonstrator

The German Demonstrator could have helped to solve the voltage violation in the event in the German grid in autumn 2018. The simulation results of this event in Figure 2.24 prove that the demonstrator tools and coordination mechanisms could have helped avoiding a voltage collapse in an extreme case, as assessed in offline simulation with different DER modes and DSO optimisation.

In the left of Figure 2.24, it is shown that reverse power flow from distribution to transmission grid (blue curve that combines the dashed and dash-dotted curve). As described above, the reduction of infeed was due to mitigation of a voltage drop event in the transmission grid. In the middle of Figure 2.24, the reactive power exchange between distribution and transmission grid is shown. In the right of Figure 2.24, the voltage on transmission grid side at DSO/TSO interconnection point. Reactive power flow and voltage are shown respectively in red curve. In both of this parts of Figure 2.24, the available flexibility potential from distribution grid is represented as the area between the two blue curves. The use of the developed optimisation tool and the provision of available reactive power flexibility can prevent such large voltage drops. It is shown that a robust available flexibility potential although the active power infeed is reduced by a large amount. Therefore, a stable support in voltage control from distribution grid for transmission grid is proven feasible and while using the tool, reduction of active power can be limited.

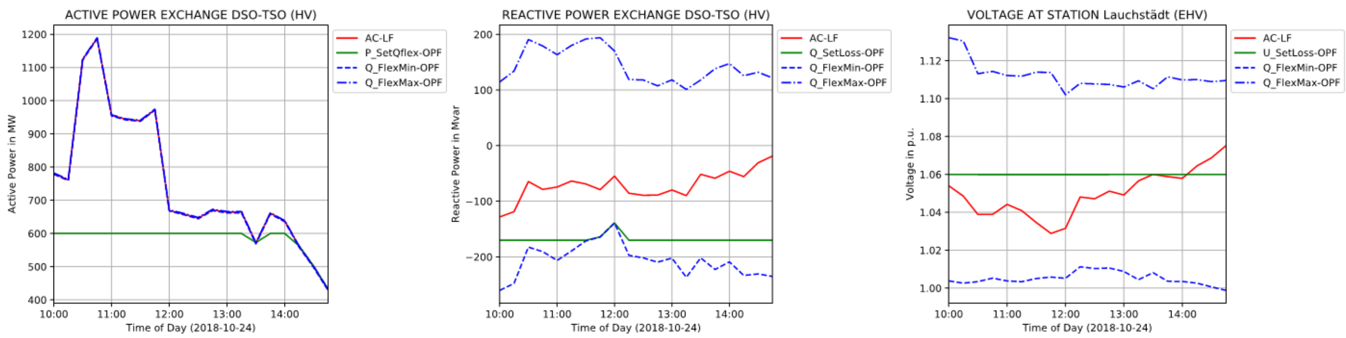


FIGURE 2.24 SIMULATION RESULTS FOR THE VOLTAGE COLLAPS IN GERMANY[4]

Proof from Italian Demonstrator

The real data acquired from the SCADA System on the Italian demonstration network shows several critical issues related to both the operating voltage and the characteristics of the network itself.

Quarto Primary Substation network is characterized by a huge penetration of DERs, which may cause back-feeding phenomena during the day and a high load at night.

Figure 2.25 shows that the measured voltage on the Green Transformer MV busbar during 5th August 2020 arose at night until 16kV, even if it was included inside the critical thresholds.

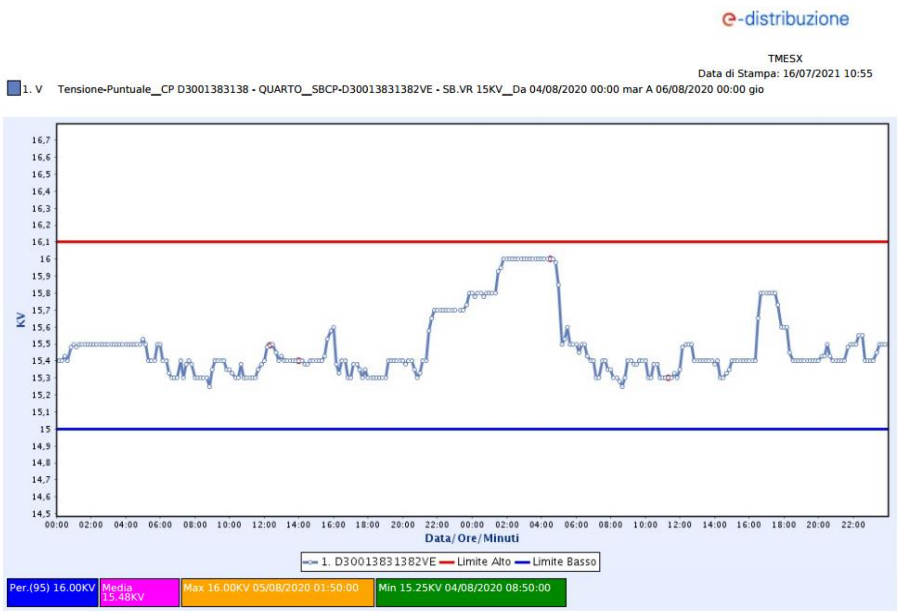


FIGURE 2.25 - VOLTAGE RECORD ON QUARTO GREEN TRANSFORMER MV BUSBAR ON 5TH AUGUST 2020..

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[4] A detailed calculation and prove of this can be found in D6.3 "Grid simulations and simulation tools - Preliminary results".

The proof of Italian demo consists of demonstrating that STATCOMs can be efficiently used within the distribution network to meet the requirements of TSO and to solve DSO local constraints, also in those moments in which PV production is not available.

Proof from Finnish Demonstrator

A novel solution to provide active power reserve to the TSO is to use a BESS. The Finnish demonstrator successfully operated an industrial and office scale BESS to provide frequency containment reserve for normal operation for the Finnish TSO Fingrid.

The Finnish Demonstrator presented a proof of concept of the local reactive power market. The successful operation of the market increased the amount of controllable reactive power resources utilized in the TSO/DSO connection point to minimize the tariff cost of the DSO and simultaneously to support the voltage in the TSO's transmission network.

3. RECOMMENDADTIONS FROM THE EU-SYSFLEX DEMONSTRATORS IN THE DISTRIBUTION SYSTEM

Based on the above outlined key messages coming from the three EU-SysFlex demonstrators in the distribution system, recommendations to distribution and transmission system operator, policy makers and regulators, as wells as market operator are derived. These recommendations can be found in the following subchapters.

3.1 RECOMMENDATIONS TO SYSTEM OPERATORS

System operators shall develop and invest in new and innovative solutions to tackle the rising system complexity.

The increasing share of renewable energy resources and the electrification of the heating and mobility sector lead to an increasing complexity of the energy system. System operators need to find new solutions to deal with it. Flexibility usage is one option to handle the scarcities of the future energy systems. As conventional flexibility resources are decreasing in amounts and new flexibility potentials arise, mostly decentralized in the distribution system, the system operators need to integrate them in their control mechanisms. This requires the system operators to develop and test new solutions, which will lead to investments in new systems, processes and technology.

System operators shall involve up- and down-stream system operators in operational planning in an early stage to ensure an efficient use of flexibilities.

There are cases where the most efficient flexibility resource is not in the same grid where the respective system needs occur. To make efficient use of all new flexibility potentials, system operators shall be able to also make use of flexibilities in some other system operators' grids and voltage levels without threatening and jeopardizing the other system operator's system operation. Therefore, system operators shall strengthen the interaction with "neighbouring" system operators. In order to design this coordination as efficient as possible up- and down-stream system operators shall be included in operational planning in an early stage.

System operator shall only request essential and imperative data from other stakeholders following the principle of data thrift to reduce complexity and improve data security.

For the coordination between system operators, information and data has to be exchanged. In order to set up this information and data exchange in a secure and manageable way, the system operators shall only request data from other system operators that is essential and imperative for the respective purpose of the exchange. Additional data and superfluous high granularity lead to unnecessarily rising complexity and threats regarding data security, as every data that is transferred presents a risk of being stolen or tampered with. These principles that support data security are described in ISO 27 001 to be used in the energy sector.

The design of flexibility processes shall be built upon the subsidiarity principle, enabling system operators to select flexible resources in their own grid and to cooperate with connecting system operators to get the most efficient flexibilities selected in their grid.

According to Electricity Directive Art. 31 and 40, DSOs and TSOs are responsible for the safety of their systems. Therefore, the selection of flexibility by a third party needs to be coordinated by them to ensure that no grid constraints are violated. If the system operator needs flexibilities in other grids, the aforementioned coordination needs to take place. Therefore, the flexibility selection process builds upon the subsidiarity principle, while still ensuring cooperation to get to a "one system approach". A flexibility process design based on the subsidiarity principle enables guarantees the connecting system operator is always involved for flexibility selection and activation ensuring grid security and reliability. Additionally, the selection of flexibilities to solve own problems should be carried out by system operators themselves in order to potentially combine this task with switching measures to find the most optimal solution and enhancing efficiency.

For ensuring the capability to handle the rising system complexity all processes, including the DSO/TSO coordination processes, shall be as far as possible automated.

New flexibility resources are mostly decentralized smaller scale assets and many of them need to be accumulated to solve the needs of the system operators. This contrasts with the conventional flexibility handling where mostly a few large assets were controlled. The handling of large amounts of flexibility resources results in higher complexity. In order to be capable to deal with this complexity and make use of the flexibility potentials, system operator shall use smart and as far as possible automated systems and processes. Without a far-reaching automation of these processes including the DSO/TSO coordination process the optimal flexibility usage and the control of the large amounts of flexibility resources will not be manageable.

System operators shall make use of their responsibility to administer the flexibility use in their own grid to fulfil their role as an active system operator.

The evolving role of the DSO to a more and more active system operator was described aforementioned multiple times. An active system operator role is implemented in the European regulation acknowledging this evolvement. In order to ensure an effective and efficient flexibility integration, all distribution system operators shall perform this designated role and therefore administer the flexibility resources in their grids.

3.2 RECOMMENDATIONS TO POLICY MAKERS AND REGULATORS

In order to increase the amount of usable flexibility resources, system operator shall be able to use all kinds of distributed flexibility resources while being technology agnostic.

The solutions to situations to be solved in the power systems, such as congestions or voltage deviations, are defined by technical parameters only. Therefore, all the resources able to fulfil the technical requirements should be allowed to contribute, regardless of their underlying technology. According to this approach, the following types of resources should be considered in order to solve system operation needs and system scarcities:

- all energy production resources
- conventional loads
- new consumers such as electric vehicles and heat humps
- batteries (via market or regulated)
- any smart combination of the above

The cost minimization principle must be applied when selecting flexibilities so that all technologies are treated in a neutral way, being solely selected based on their price and technical characteristics. DSOs shall be able to make use of demand response, storage and generation in a neutral way.

System operators shall be incentivized to make use of distributed flexibility in order to minimize the curtailment of RES and integrate EVs and heat pumps as efficiently as possible into the energy system.

According to Art. 32 of the Electricity Directive, Member States shall incentivize DSOs to procure flexibility services to improve the efficiency of their networks and to integrate more renewable energies into the energy system. This directive had to be transposed into national law by beginning of 2021. This is already European law as part of CEPP. All new laws should continue being based on this principle.

A legal framework has to be established to incentivize system operators to develop and invest in new and innovative solutions benefiting public welfare.

On the one hand, the development of new solutions is necessary for system operators to ensure the safety and reliability of the energy supply. On the other hand, the current regulation could hinder system operators from developing innovative solutions that can benefit public welfare if their remuneration mechanisms are not adequate.

For example, the remuneration schemes encourage the system operators to resort to grid enhancement, such as new cables and overhead lines, instead of exploiting existing flexible resources. The costs for system stability could be reduced if the use of flexibility resources were included in the development and testing stages, but also during the system operation.

To underline this, so far in the Finnish regulation the DSOs are encouraged to resort to investments instead of purchasing flexibility services. When aiming to increase the use of flexibilities in the networks with more renewable energies, the regulation model should value the purchase of flexibility services similarly to investments.

A legal framework shall be establish allowing regulated approaches where market based approaches are not feasible or reasonable.

In many cases, and as a general principle, the market-based approaches can be seen as an efficient solution. They reach their limits in cases where risks of gaming due to little competition or risks due to inherent system properties occur. In those cases, a regulated approach shall be established that is in line with European law and attempting to benefit public welfare.

For example, regulation in Germany for congestion management by using generation flexibilities only: If at energy market sold energy is reduced to mitigate congestions, the needed balancing is executed by the system operator. By regulation marginal costs are used and a market approach without such scheme cannot be more efficient plus it would be more complex. Therefore, such market approach is no favoured solution from public welfare aspects as long as generation fulfils the requirements in flexibility need. On the other hand, if integrating flexibility from consumption because it could be more efficient than marginal costs of generation, a regulated cost scheme cannot be applied because of the heterogeneity of possible flexibility providing applications. Therefore a market approach could be a less complex and more efficient solution. In this case, there is the risk that resource operators could boost the prices and use their market power in a system with limited liquidity, the mitigation of such gaming risk must be supervised. To mitigate such risks regulation schemes must be introduced that could increase the complexity to a level to where such a market approach is no favoured solution anymore.

When adapting legal frameworks, policy makers shall coordinate with all different stakeholders in order to establish effective and efficient frameworks.

In order to ensure that the regulatory framework supports an efficient and reliable energy supply, the regulatory authorities and the affected stakeholders should coordinate their efforts. An aspect of this is also to uncover barriers in the development of efficient innovative solutions. The coordination is already quite active today, but the regulatory authorities should constantly question whether it is sufficient to tackle the current and future challenges.

Flexibility processes shall build upon the subsidiarity principle: Each system operator shall be able to select the flexibilities for its own needs in its own grid and coordinate with connected system operators to find the most suitable flexibilities where necessary.

Regulation of flexibility selection processes must be consistent with the responsibility of system operators. Active system management needs to be carried out by system operators and coordination among them can take place on a bilateral way via standardized interfaces. The demonstrators have shown that such decentralized optimization including TSO/DSO coordination is very efficient to create synergies across voltage levels. A centralized optimization would undermine regulatory principles and cause new challenges without providing significant benefits.

Flexibility processes shall only foresee data exchanges for essential and imperative data between stakeholders following the principle of data thrift to reduce complexity and improve data security.

Policy makers and regulatory authorities should always consider the basic data thrift principle. Data that is not collected, stored and exchanged cannot be compromised. This implies that the regulatory authorities should encourage data use that minimises the risks, but allows the fostering of new data-driven solutions by questioning the sufficiency and adjusting the regulatory framework if needed.

Decentralized optimization, building upon the principle "local before regional", is best suited for regions where the DSO also needs locational products to run their grids efficiently. Due to the current trend of decentralization and decarbonisation, it can be assumed that this will be nearly everywhere the case.

A centralized flexibility selection process is only suitable where the impact of such flexibility on DSO grids is sufficiently static and can be depicted within a grid prequalification so that no distribution grid constraints are violated when such flexibility is activated. This might be the case for inertia or FCR, where the short duration hardly jeopardizes thermal constraints. For these reasons, a decentralized approach is, in most cases, most suitable and safe. In a general way, the "local before regional" or "bottom-up" principle proves to be the best principle, depicting the natural structure of the grid.

Building on the principle "local before regional", optimisation done in the sphere of the connecting system operator ensures that the connecting system operator is always involved for flexibility selection and activation guaranteeing that the system operator can fulfil his responsibility of ensuring grid security and reliability in its grid.

The option of a joint procurement of flexibility for congestion management and balancing must be carefully assessed, since it can lead to higher inefficiencies than separate procurement and more regulatory challenges.

The design of a joint product for congestion management and balancing can lead to higher limitations for both scarcities. The possible aggregation of different resources for such a product is highly limited due to the local nature of congestions. Additionally, the needed activation time of such product reduces the flexibilities available for congestion management. With this, the urgently needed integration of demand response and electrical storage as flexibilities for congestion management might partly be blocked, since these technologies mostly need advanced preparation time for such an activation. These disadvantages of a joint procurement must be balanced against advantages such as reduced transaction costs and synergy potentials. Overall, a higher social welfare of a joint procurement is not a given thing.

3.3 RECOMMENDATIONS TO MARKET OPERATORS

When establishing flexibility markets, market operators and the foreseen market design shall respect existing roles and their responsibilities.

Based on the needed data for executing of functionalities and the data thrift principles, every involved stakeholder should be able to execute their own responsibility without hindering other stakeholders to do so. Therefore, market design shall not reduce the capability to perform tasks according to existing roles responsibilities.

When establishing flexibility markets, market operator shall enable the selection of flexibility by system operators by developing flexibility order books.

The discussion of the clearing of flexibility markets is mostly based on the design for wholesale and balancing markets. The situation for locational flexibility need is different and more challenging, since congestions do not only occur on few interconnections and transmission grid elements, but across all voltage levels downstream the much larger distribution grid. Therefore, the computational effort of a centralized clearing is much more complex and challenging, especially considering that switching measures in the network can lead to solutions that are more efficient.

Additionally, the responsibility of system operators is to ensure the safety of their systems. To do so they would have to approve every result of a market clearing that would affect them, i.e. if the market operator does the selection of flexibility a doubled system at the system operator needs to validate the solution to ensure reliability of grid operation. In order to be compliant with such responsibility, reduce complexity, avoid duplicated IT systems and reduce regulatory challenges, flexibility markets should be designed in a way allowing system operators to select the appropriate flexibilities in an order book (similar to continuous trading). The order book is connecting system operators and flexibility service providers allowing the system operators to select the best offer to activate the needed flexibility service for congestion management and voltage control in an efficient way without jeopardising with grid operation.

When establishing flexibility markets, only data exchanges for essential and imperative data between stakeholders shall be exchanged, according to the "data thrift" principle, to reduce complexity and improve data security.

Market design should always consider the basic data thrift principle. Data that is not collected, stored and exchanged cannot be compromised. When establishing flexibility markets, market design should consider the use of critical data in the sphere of the stakeholder responsible for this critical data. This supports reducing complexity and risk of compromising.

When establishing flexibility markets, market operators shall develop methodologies, such as market monitoring, to mitigate strategic gaming.

Strategic gaming is the major blocking point for market-based procurement of locational products, especially in market areas that face a lack of liquidity. Doubts are high at the side of regulators and policy-makers. Mitigation measure should be developed and tested in a "real world" environment, i.e. outside of short-running R&D projects, in order to prove such concepts and convince regulators that no derogation from the market-based principle is necessary.

When establishing flexibility markets, market operators shall allow a wide variation of flexibility bid description based on standardized parameters, including the possibility to address rebound effects.

Where the flexible behaviour of generation can be highly standardized, demand response characteristics are much more heterogeneous. Standardization is key for efficient processes, but there is a trade-off with the exclusion of flexibility service providers. Since liquidity is a major issue for congestion management and voltage control, such trade-off must be assessed with care. Nonetheless, the standardization of parameters is possible. It should include the description of the rebound effect, which is a necessary characteristic for efficient congestion management processes.

Active power reserve markets to be harmonized with same minimum bid size

The minimum size of bids of the different markets should be harmonized and taken as low as computationally possible to promote the participation of smaller scale assets.

For example, today the minimum bid size in Fingrid's FCR-D market (disturbance) is 1 MW and in the FCR-N market (normal operation) the bid size is 0.1 MW. This limit is high for low power decentralized resources, such as EV-charging, as a large amount of single assets are required to be aggregated to meet the power limit. Therefore, a lower bid limit would be beneficial with decentralized assets and also the two FCR markets would be in line with market offers.

4. COPYRIGHT

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

ANNEX I. REFERENCES TO DETAILED DEMONSTRATOR DELIVERABLES

[D6.1] Demonstrators' system use cases description

[D6.2] Forecast: Data, Methods and Processing. A common description

[D6.3] Grid Simulations and simulations tools. Preliminary results

[D6.4] General description of the used data as a basis for a general data principle

[D6.5] Optimization tools and first applications in simulated environments

[D6.6] Demonstrators for flexibility provision from decentralised resources, common view

[D6.7] German demonstrator - Grid node based optimization

[D6.8] Italian demonstrator - DSO support to the transmission network operation

[D6.9] Finnish demonstrator - Market based integration of distributed resources in the transmission system operation