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Demonstrators for Flexibility Provision from Decentralized Resources, Common View

D6.6

EU-SysFlex

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ABBREVIATIONS AND ACRONYMS

AMR	Automatic Meter Reading
BESS	Battery Energy Storage Systems
DER	Distributed Energy Resources
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)
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
R&D	Research and Development
SCADA	Supervisory Control and Data Acquisition
STATCOM	Static Synchronous Compensator
TSO	Transmission System Operator
WP	Work Package

EXECUTIVE SUMMARY

The EU-SysFlex H2020 project aims at a large-scale deployment of solutions, including technical options, system control and a novel market design to integrate a large share of renewable electricity, maintaining the security and reliability of the European power system. The project results will contribute to enhancing system flexibility, resorting to both existing assets and new technologies in an integrated manner, based on seven European large-scale demonstrators (WP 6, 7, 8 and 9). The overall objective of WP6 is the analysis of the exploitation of decentralized flexibility resources connected to the distribution grid for system services provision to the TSOs, by the means of three physical demonstrators located in Germany, Italy and Finland.

Following the objectives of the EU-SysFlex project and of its WP6 in particular, the three demonstrators are being set up in order to show how resources connected to the distribution system can help address system needs by providing ancillary services to the transmission level and at the same time meet the requirements of both TSO and DSO while, also, improving the coordination between these two actors.

The demonstrators are located in distribution networks with different characteristics and in different countries with their own system needs and regulations. For that reason, their set-ups and frameworks are different but as they pursue the same general objectives, they are complementary in displaying the various possibilities for addressing system needs in the distribution and transmission grid with the help of distributed flexibility resources connected to the distribution grid.

The German demonstrator enables the provision of flexibilities from the high voltage grid to the TSO and for the DSO’s own use. The aim is to integrate RES connected to the high voltage level of the distribution grid into the schedule-based process for congestion management and voltage control in the transmission grid while considering the interdependencies between active and reactive power flexibilities of these units. Therefore, the overall objective is to establish a new process and coordination for congestion management and a new automated tool for voltage control and reactive power management. To do so, the German demonstrator estimates a possible flexibility range of active and reactive power at grid nodes at the DSO/TSO interface in order to provide these as an ancillary service to the TSO for congestion management and voltage control in the transmission grid.

The Italian demonstrator is built upon recent improvements in the DSO’s control and monitoring system. The primary aspect that will be demonstrated is how the local assets controlled by the DSO can be integrated in the control systems in a way that allows the distributed resources to participate to voltage management while optimizing the operation of the distribution grid they are connected to. In addition, a similar approach aiming at making it possible for the distributed resources to better participate to frequency control and congestion management will be taken into account and simulated.

The Finnish demonstrator brings in the market aspects of providing services from distributed resources. On one hand, it will aggregate small distributed resources into the transmission level markets for frequency management. On the other hand, it will study a market-based approach for a DSO to purchase reactive power control possibilities.

An analysis of how the three demonstrators complement each other shows the possibility of using various flexibility resources connected to voltage levels ranging from low to high voltage in order to provide services and solve a set of scarcities such as frequency deviations, voltage violations and congestions. The demonstrators also show different technical strategies to improve the coordination between the TSO and DSO when tackling those scarcities. When working hand-in-hand the demonstrators display the technical chain allowing to connect and more efficiently operate distributed assets. Furthermore, they show how those resources can be aggregated and made available to the TSO and DSO both by coordination mechanisms and by using market-based mechanisms.

1. INTRODUCTION

1.1 BACKGROUND

The EU-SysFlex project seeks to enable the European power system to utilise efficient, coordinated flexibilities in order to integrate high levels of Renewable Energy Sources (RES). One of the primary goals of the project is to examine the European power system with at least 50% of electricity coming from RES, an increasing part of which from variable, distributed sources connected through a power electronic interface, such as wind and solar.

In order to achieve the project‘s objectives the consortium pursues the identification of technical shortfalls requiring innovative solutions, the development of novel market designs to provide incentives for these solutions, and the demonstration of a range of innovative solutions. Other activities such as data management analysis, innovative tool development and integration and testing of new system services in TSOs’ control centres are also included in the project approach. The project‘s results will contribute to enhance system flexibility, resorting both to existing assets and new technologies in an integrated manner, based on seven European large scale demonstrators in Germany, Italy, Finland, Portugal (2), France, and the Baltic states (WP 6, 7, 8 and 9), as well as the experience feedback of Ireland, forerunner in terms of operating with high wind share in the power system (WP4).

Work Package (WP) 6 *“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, in coordination between DSOs and 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 level. Scarcities of interest have been identified earlier in the project (D2.1: State-of-the-Art Literature Review of System Scarcities at High Levels of Renewable Generation [1]). It should be noted however that the demonstrators address only scarcities that are currently presenting themselves in the environment in which they are set up.

1.2 WP 6 OBJECTIVES AND PURPOSE OF TASK 6.4

The primary objective of WP6 is to analyse and test the exploitation of decentralized flexibility resources connected to the distribution grid, respecting to the needs of both DSOs and TSOs. Due to the current policies for the decarbonisation of the energy systems, RES capacities are increasing, especially in the distribution network, that has not been designed to host large volumes of generation capacity, when, at the same time, they have to guarantee the security and resilience of their networks. A consequence of this is their need for adequate leverage in their network operation in order to avoid congestions and constraints violations. At the same time, the amount of traditional flexibility resources, historically provided by conventional generation in the transmission level, decreases. Therefore, the use of flexibility resources in the distribution grid, to guarantee security and resilience in the transmission system operation, is increasingly asked for.

According to this, three sub-objectives have been 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.

WP 6 addresses these objectives through five interlinked tasks. Task 6.1 is related to needed Work Package coordination. Task 6.2 focuses on the definition of System Use Cases (SUC) based on the Business Use Cases (BUC) defined in WP3. Within Task 6.3 systems and tools are being developed in order to set up the SUC. Within Task 6.4 the demonstrators are being set up and field tests will be carried out. Furthermore, the results of these field tests will be analysed and common conclusions will be drawn in Task 6.5.

The activities and achievements of each Task, and of the whole Work Package itself, will be presented through a comprehensive set of deliverables. This deliverable D6.6 gives an overview of the demonstrators. Each demonstrator will be the object of another deliverable (D6.7 to D6.8), which are going to be published towards the end of the EU-SysFlex project, including details about the implementation performed and the results obtained. D6.6 therefore aims at giving a common view on the three demonstrations, underlining the common objectives and their complementarity.

The deliverables for Task 6.4 are shortly listed in the following:

- Deliverable 6.6 – *"Demonstrators for flexibility provision from decentralised resources, common view"*
- Deliverable 6.7 – *"German demonstrator – Grid node based optimization"*
- Deliverable 6.8 – *"Italian demonstrator – DSO support to the transmission network operation"*
- Deliverable 6.9 – *"Finnish demonstrator – Market based integration of DR in the transmission system operation"*

1.3 STRUCTURE

This deliverable is structured in two main parts. The first part is composed of three chapters, detailing an individual description of each demonstrator. At first, the general objective of the demonstration is presented and the status quo, i.e. the situation when the demonstrator starts, is explained to underline in which framework the demonstration is situated. Then, the external and internal drivers for the demonstration are listed, and previous projects on which the EU-SysFlex demonstrators are built upon are presented. Next is an outline of the innovative character of the demonstrations. Based on that, the environment of the demonstrator and the tools that will be developed during the project are described. Finally, the applicability and limitations of the demonstrators are explained and the expected results are presented.

In its second part, the deliverable looks at the demonstrations from an overall perspective. It emphasizes the common view, showing where the demonstrator complement each other. Furthermore, it analyses how the three different demonstrators could work hand in hand in theory, also in the same grid infrastructure and complementarily work together.

2. THE GERMAN DEMONSTRATOR

Overall Objective

- *New process and coordination for congestion management*
- *New automated tool for Voltage Control and Reactive Power Management*

Status Quo

- *Risk of counter actions due to insufficient TSO/DSO coordination*
- *Exhausted current capacities for congestion management*
- *Increasing costs for congestion management*

Drivers

- *Increasing share of RES*
- *Insufficient TSO/DSO Coordination*
- *Shortage of today's redispatch potential*
- *Structural changes of the power system*
- *Cost-efficiency*

Previous Projects

- *"PG FHWM" – a cooperation of the major DSOs underlying the TSO 50Hertz and 50Hertz itself for active power flexibilities*
- *"SysDL2.0" – a national R&D project for reactive power flexibilities*

EU-SysFlex Innovation

- *Including RES dispatch in congestion management*
- *Set up of new coordinated process for congestion management*
- *Automated tool for voltage Control and Reactive Power Management*
- *Integrating new and improved forecasts for RES generation and load*

Environment

Grid:

- *110 kV meshed grid*
- *16 Network connection points with 40 transformers to TSO*
- *55 underlying DSOs with 186 interconnections to the HV grid of MITNETZ STROM*

High shares of RES:

- *8.5 GW RES of 10 GW of total installed capacity*
- *98% share of RES compared to the electricity consumption*

Potential Flexibilities:

- *5.2 GW potential flexibilities: 2.7 GW wind, 1 GW solar and 1.5GW conventional sources*
- *For reactive power between -350 Mvar and +280 Mvar is usable*

Tools

- *Grid topology analysis and processing*
- *State estimation*
- *Forecast network states*
- *Active power loss optimization*
- *Reactive Power Coordination*
- *Active Power Coordination*
- *Congestion Management*
- *PQ-Mapping*

Applicability and Limitations

- *Possible application to different voltage levels*
- *Limitations due to regulation*

Expected Results

- *Developed and proved active & reactive power management process to include RES from distribution grids*
- *Proof of concept of coordinated TSO/DSO congestion management*
- *Feasibility of fully automated process of a combined grid optimization (P and Q)*
- *More accurate RES feed-in and load forecasting*

2.1 GENERAL OBJECTIVE

Research object

The German demonstrator will estimate a possible flexibility range of reactive power at grid nodes at the DSO/TSO[1] interface, and of active power at the unit level, in order to provide these as ancillary services to the TSO for congestion management and voltage control in the transmission grid. Furthermore, the demonstrator disaggregate these estimated values at generating unit level to enable the addressing and use for distribution grid purposes. This estimation does not exist today in a forecasted way. The aim is to integrate RES connected to the distribution grid into the schedule-based process for congestion management and voltage control in the transmission grid while considering the interdependencies between active and reactive power flexibilities of these units.

One main research object is to estimate the future grid states based on grid simulations and improved forecasts as well as the interferences (e.g. restrictions, dependencies or disturbances due to load flow) in the meshed grid in order to foster a transparent coordination at the TSO/DSO interface. The demonstrator is following a new approach. The new approach considers the availability (including load and generation forecasts) and cost (today regulatory fixed compensation and, in the future, potentially bids from a flexibility) of flexibility. In addition, the approach considers the impact on the requested operating point in the network as a flexibility activation changes the technical sensitivities in the grid. This approach will find the most efficient solutions concerning costs and impact when managing active and reactive power requests from the TSO, considering system stability and optimization of the whole power system (both in the transmission and distribution grid).

Goal of the Demonstrator and expected benefits

The goal of the demonstrator is to result in a more accurate estimation of the power network state and its predicted future states. With the knowledge of the power flow in the distribution network, a more realistic flexibility range of active and reactive power can be offered to the TSO. This will result in requests that are more accurate from the TSO leading to less corrective actions such as curtailment of the PV, which can lead to high costs due to the fact that currently a lot of PV units are not equipped to react to curtailment requests. In a test by a German DSO, Bayernwerk, only 25 % of the PV units fulfilled the request [2]. The communication and coordination between TSO and DSO will also be improved due to direct insight for the TSO in the available flexibility ranges from the distribution grid via the demonstrator interfaces.

[1] In Germany the interface DSO-TSO is at the HV/EHV transformer between the 110kV and 220kV or 380kV level.

2.2 STATUS QUO

Congestion Management today

In normal operation, foreseen congestions in the transmission grid are managed with redispatch measures according to § 13.1 of the German Energy Industry Act (Energiewirtschaftsgesetz – EnWG [4]) applied only to conventional power plants connected to the transmission grid. Formally, there is also the possibility to include conventional plants (> 10 MW) connected to the distribution grid in this process, but in reality this is rarely done. If the redispatch potential is not sufficient, the next step is the feed-in curtailment according to § 13.2 of the German Energy Industry Act. In this process feed-in from RES is reduced as an emergency measure. This curtailment is realized first via RES connected to the transmission grid, and only after that via RES connected to the distribution grid. The process is set up in such a way that the TSO issues a request for feed-in curtailment to the DSO. It is then the responsibility of the DSO to actually fulfil the measure. This process of the congestion management today regarding solving congestion in the transmission grid is visualized in Figure 1.

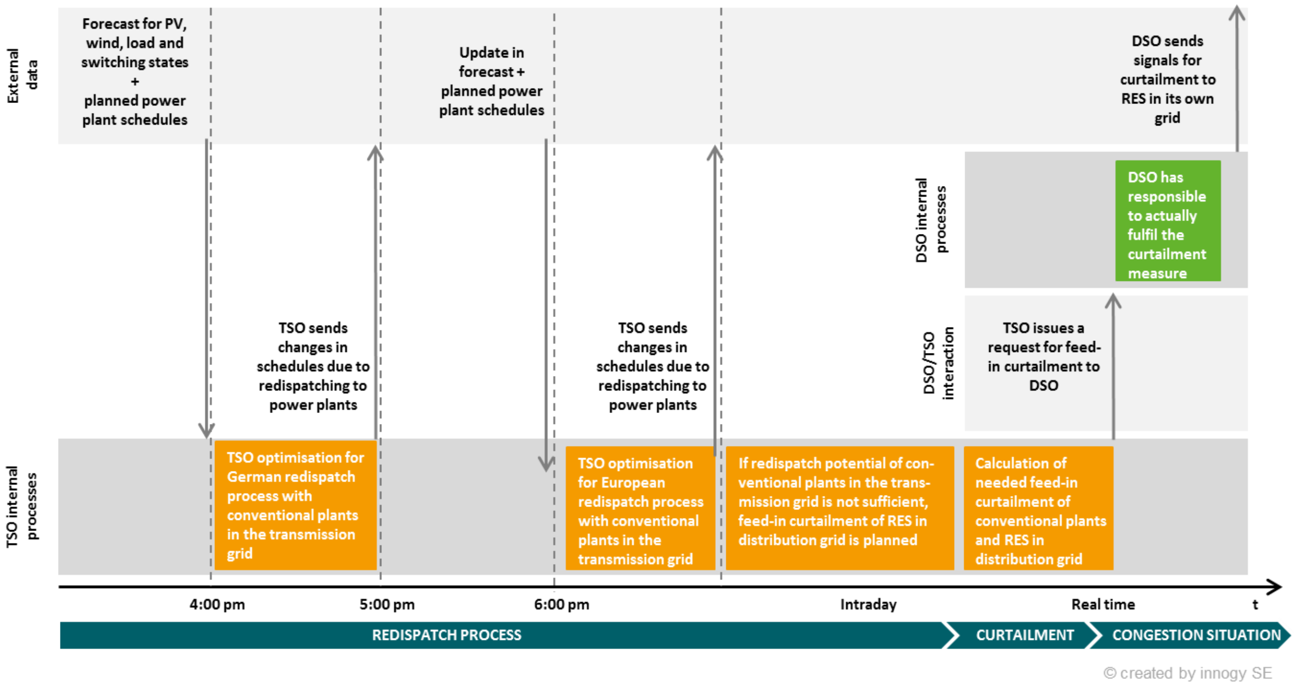

FIGURE 1 - PROCESS OF THE GERMAN CONGESTION MANAGEMENT TODAY

Limits of today's congestion management

The increasing share of RES and the additional delays in Germany's planned grid expansion projects make transmission system operators (TSOs) already face challenges in day-to-day grid operation and operational planning. It has become increasingly common that TSOs are forced to apply remedial measures at short notice such as redispatching in order to relieve grid congestions. In situations with high feed-ins of RES, a sufficient number of power plants suitable for redispatching in operation is not always available. The feed-in curtailments of RES according to § 13.2 of the German Energy Industry Act, which are supposed to be emergency measures, are used in addition. Unlike redispatch measures curtailment is not an energetically balanced measure and therefore needs additional balancing measures, such as balancing power. This results in compensational payments to curtail RES plants (estimated to 610M€ in Germany in 2017 [3]) and, in addition, payment for the balancing energy needed. This causes a double payment, although the congestion was predicted and foreseen. Furthermore, these current solutions to deal with shortage of congestion management measures for the transmission grid are already reaching their technical and economic limits.

Voltage Control and Reactive Power Management today

Today's voltage control at the interface between the TSO and the DSO consists of two tools. One tool is to activate/deactivate an inductor at the interface. The other tool is to use the on load tap changer (OLTC) on the EHV/HV transformer. Both tools are controlled by the TSO, but used in coordination with the DSO. The coordination process is done by phone. The operator who needs the flexibility calls the other party to coordinate the use of the flexibility. Detecting the need is close to real time. The DSO uses OLTC at HV/MV-substations as well with an automatic setting to adjust the voltage to a defined range in MV. Due to a large share of infeed from distributed energy resources (DER), the limited operating range of the OLTC is insufficient compared to the needed flexibility. The full potential of the OLTC is already in use for voltage control. Therefore, additional methods of providing reactive power flexibility are needed.

This coordination is needed whenever the predicted voltage at the TSO/DSO interface is estimated to be out of the operational band meaning that the predicted voltage is either higher than the upper bound or lover than the lower bound. A generalized example is illustrated in Figure 2.

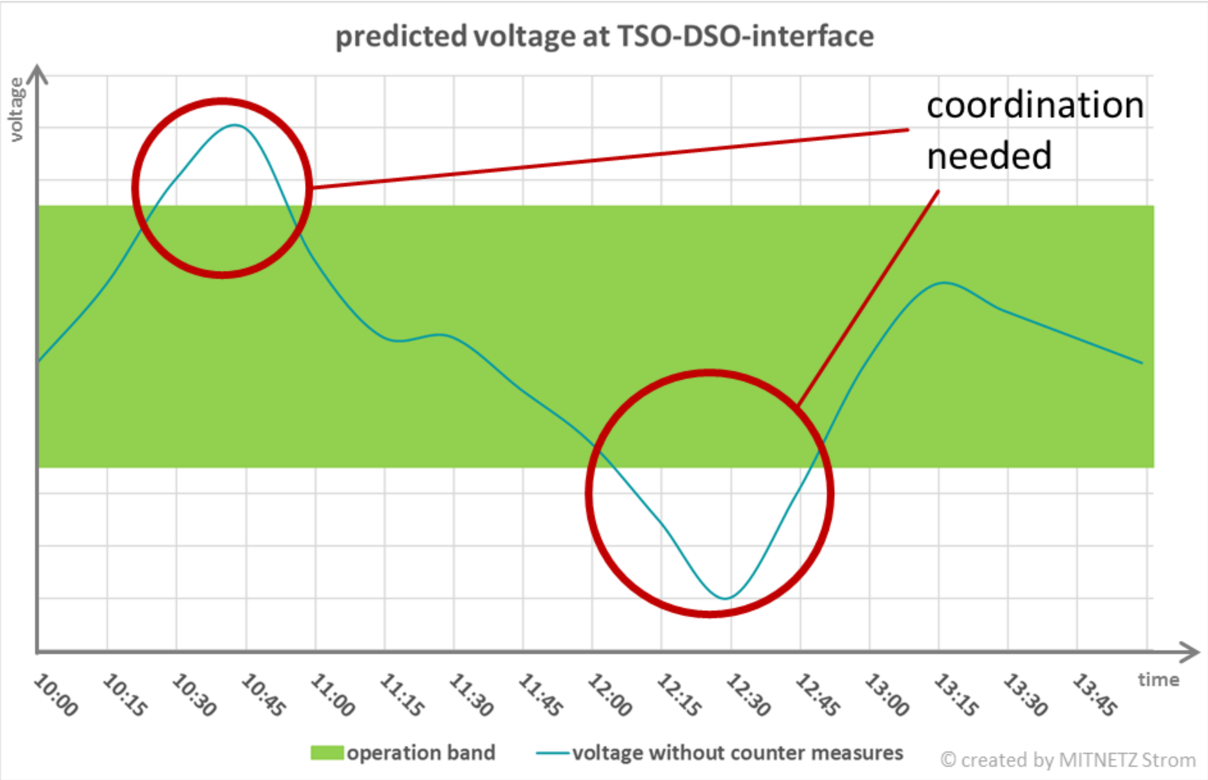

FIGURE 2 - PREDICTED VOLTAGE AT TSO/DSO INTERFACE

Dynamic local voltage control in the distribution grid is not considered as flexibility between TSO and DSO, although it has the potential to be a third tool. Today TSOs can also adapt the power factor of big conventional power plants or grid assets like a phase shifter or Static Synchronous Compensator (STATCOMS) for voltage control in the transmission grid and the DSO uses static settings or in some cases dynamic settings for local voltage control in distribution grid. If the voltage settings and the reactive power flow at the interface between TSO and DSO are within a defined range, there is no coordination between the two parties regarding reactive power management in the respective grid and the operators make sure to keep the settings in this range.

Limits of Today’s Voltage Control and Reactive Power Management

The usage of these two existing tools for voltage control depends on the availability of a sufficient amount of reactive power flexibilities in extra high voltage (EHV). Dependencies on conventional plants in the EHV level does not fit into a future power system with an increasing share of RES that is mainly connected to the HV and lower voltage levels. These distributed energy resources (DER) are displacing consequently and decreasing the amount of flexibilities from EHV grid connected plants. In the future, dynamic local voltage control can help as a third tool besides the above explained tools using only grid assets for voltage control. The limited coordination between TSO and DSO regarding reactive power management leads to limited settings for voltage control.

2.3 INTERNAL AND EXTERNAL DRIVERS

Multiple drivers constitute the basis for the German Demonstrator, which can be distinguished between internal and external drivers. Internal drivers are situations, events or decisions that occur inside the business and are therefore under control of the company. External drivers on the other hand are situations, events or decisions that occur outside of the company. The external and internal drivers of the German Demonstrator are displayed in Figure 3.

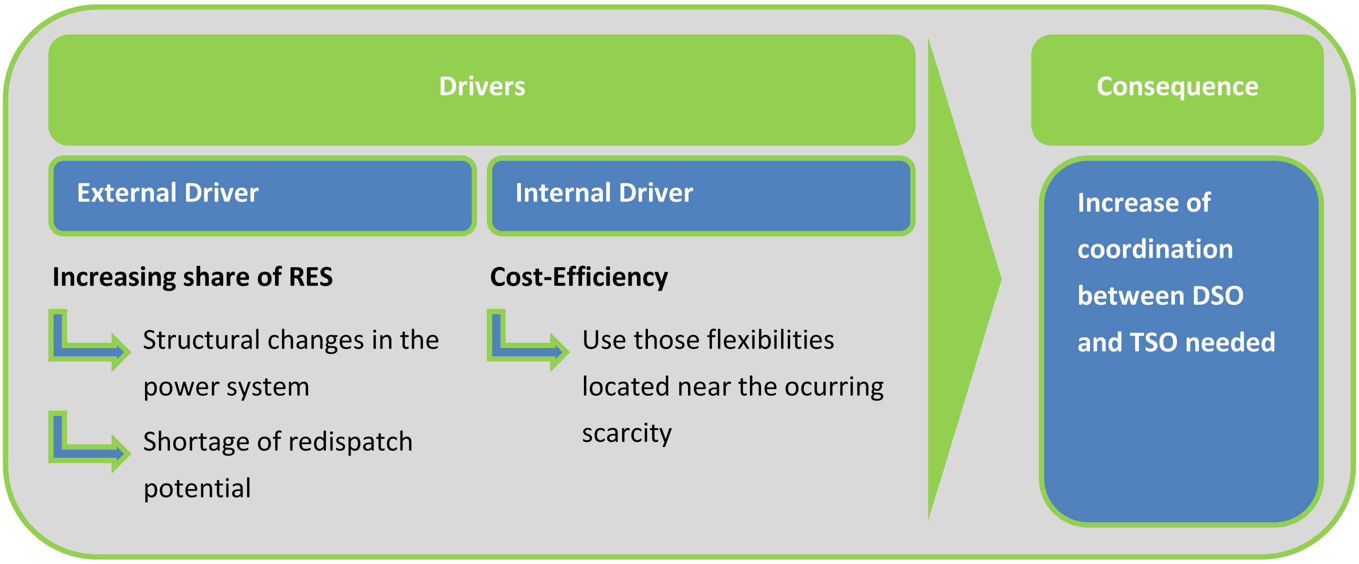

FIGURE 3 - DRIVERS FOR THE GERMAN DEMONSTRATOR

External Driver: Increasing share of RES

Already in 2017 Germany had a share of roughly 40 % [5] of renewable energy resources (RES) regarding the net electricity generation. In 2030, an even higher share of RES is expected, as the government aims at 65% RES in 2030 as stated in the legal amendment of the German Renewable Energy Act (EEG) in 2017 [6]. This raising share of RES in the system leads to significant structural changes of the power system.

The generation from RES will continue to increase in the future, and therefore the number of conventional power plants will decrease and it will result in a more decentralised power system. Due to this, the flexibility potential in transmission grid will face a strong decrease. Therefore, some flexibilities will have to be provided by RES, a large share of which are connected to the distribution grid. In Germany, the distribution grid covers voltage levels from 110 kV down to low voltage. Most of the RES are connected to the same infrastructure as most of the consumption. The HV distribution grid is built as a meshed grid and this means that the sensitivity and impact of generation units on e.g. the interconnection to the TSO depend on load flow and grid topology.

This increasing share of distributed RES leads to higher requirements in congestion management for both TSO and DSO. Already today, events occur that cause congestion both in the TSO and in the DSO grids. An exemplary situation for that is when the use of conventional power plants in the distribution grid for reserve requirements (frequency control or frequency restoration) by the TSO causes congestion in the distribution grid. In this case, there is a risk that if TSO and DSO do not coordinate their actions, the DSO solves this congestion e.g. by reducing production of RES in the distribution grid, counteracting the measure for reserve requirements taken by the TSO.

The increase of the share of RES also leads to a shortage of today's redispatch potential. If units fed in as traded by commercial aggregators (who set the schedule), without the TSO performing redispatch (setting a new schedule), many lines would show congestion in the grid (see for example red transmission lines in Figure 4).

FIGURE 4 - 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 already in the (n-0)-case (red bubbles in Figure 5). The goal is to always reach a line loading of less than 100% in the (n-1)-scenario to fulfil the (n-1)-criterion. Including RES connected to the distribution grids in the redispatch process, would increase the redispatch potential to achieve a line loading in the transmission grid to be lower than 100% for the (n-1)-scenario.

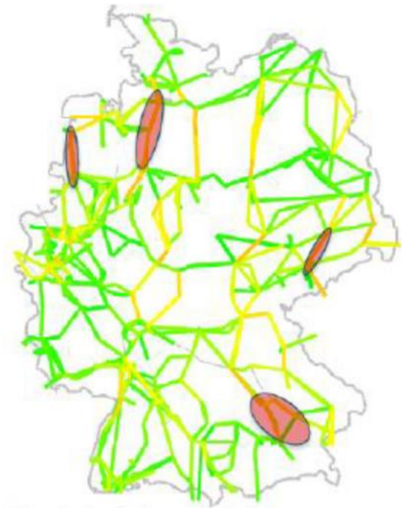

FIGURE 5 - GERMAN TRANSMISSION GRID AFTER REDISPATCH (SOURCE: BNETZA, GERMAN REGULATORY AUTHORITY, 2017)

Additionally, the increasing share of RES is leading to higher requirements for voltage control. The event from 24.10.2018 where around 1 GW of infeed was curtailed as an emergency measure in the HV grid of MITNETZ STROM because of voltage violation in the EHV grid caused by significant forecast deviation stipulates these increasing requirements. Reactive power flexibility could not be used due to lack of knowledge of reactive power flexibility potential in distribution grid. Therefore, such a high amount of active power needed to be curtailed. The system for enabling reactive power flexibility provision to the TSO from the distribution grid connected flexibility resources will be developed in EU-SysFlex German demonstration within the WP6.

Internal Driver: Cost efficiency

The German Demonstrator will show how to use all possible generator flexibilities in the DSO grid in order to solve grid congestions in the TSO and DSO grid in the most cost-efficient way. For cost-efficiency, the amount of needed flexibilities can be reduced if flexibilities are close to where the congestion is occurring. Under today's regime for congestion management, the costs will increase, also caused by the needed balancing. The costs for congestion management in 2017 reached a new record of 1.4 billion € [10].

Reactive Power flexibilities for voltage control face the same technical problem, but todays needed amount is provided via the regulations in grid connection contracts between Generation Operator and System Operator, so that there are no flexibility costs. In the future, it is possible, that the needed amount rises above the potential available via grid connection contracts. The use of flexibilities for voltage control will also be shown in the German Demonstrator.

Consequence: Increase of coordination between TSO and DSO is needed

Summarized, the main drivers considered in the German Demonstrator are external drivers, namely the increased share of RES, especially volatile RES like wind, not located close to the demand sites and increasingly connected to the distribution grid, which leads to a structural change in the power system. That leads to higher requirements for congestion management and at the same time to a shortage of redispatch potential in the transmission grid. Uncoordinated measures of the TSO and DSO can lead to counteracting measures. From that arise the technical needs of active and reactive power flexibilities for congestion management and voltage control as well as the regulatory requirements for a cost-efficient process. To achieve a cost-efficient process, coordination is needed, that consider all constraints for TSO as well as for DSO.

2.4 PREVIOUS PROJECTS

To face the challenges derived from these drivers, previous projects were already set up before the start of the EU-SysFlex project. The German Demonstrator builds up on their results.

PG FHWM for Active power Flexibilities

The problem, i.e. the redispatch potential in the transmission grid needed for measures according to § 13.1 of German Energy Industry Act is exhausted, has been analysed within the PG FHWM ("Projektgruppe Frequenzhaltung und Wirkleistungsmanagement" meaning project group for frequency control and active power management). This project group consists of DSOs, who control a 110 kV grid within the control area of the TSO 50Hertz, and 50Hertz as the TSO.

In today's process, emergency measures such as the feed-in curtailment of RES, are used to deal with this shortage of redispatch potential. In order not to have to constantly use emergency measures according to § 13.2 it was an initiative of the PG FHWM including 50Hertz and MITNETZ to define and test measures for solving congestions in the transmission grid using RES connected to the distribution grid. For these measures, different possible processes were jointly defined. One defined option was to set-up a process analogous to the process for curtailment of RES in the distribution grid, but with a request sent as soon as the congestion and needed measure are foreseen. A request is sent per network connection point of the TSO and DSO. The DSO then decides on how to fulfil the request. The legal basis for this process is still missing for RES. Within PG FHWM a pilot test was set up and successfully conducted with two direct marketers. However, the process in this test was a manual process within Excel.

The result of this project, a manual process, is the basis for the German Demonstrator of EU-SysFlex. It will be further developed in the German demonstration in EU-SysFlex to enable the provision of active power flexibilities from the distribution grid to the TSO. Therefore, the needed information and processing functionalities will be developed and tested in a field test to evaluate the feasibility of an automated process.

SysDL2.0 for Reactive Power Flexibilities

SysDL2.0 was a project including 50Hertz as TSO and MITNETZ as DSO and many more partners to test preliminary ancillary service products for voltage control and reactive power management in the transmission grid with the help of RES connected to the distribution grid. The established test system took into account all network restrictions (e.g. (n-1)-criterion) and was implemented prototypically. This test system was set up to calculate the flexibility potential of reactive power from the distribution grid over the whole day but without a direct connection to the control system. Instead, a user interface was created, where measures were suggested and could be manually transferred from the parallel test system to the active control system. Various tests were carried out such as providing specific voltage and providing reactive power as required in real time operation. Results show that these services can be provided by the DSO. Nevertheless, the set up test system was 20 minutes behind the process. This shows that the manual operation is not feasible for a high number of flexibility units and that further automation is necessary.

This project is the basis for the German Demonstrator of EU-SysFlex. It will be further developed in the German demonstration in EU-SysFlex to enable the provision of reactive power flexibilities from the distribution grid to the TSO. Therefore, the needed information and processing functionalities will be developed and tested in a field test to evaluate the feasibility of an automated process.

2.5 EU-SYSFLEX INNOVATION

The innovation of the German Demonstrator in general is including RES in congestion management by setting up a new and coordinated process for congestion management and developing an automated tool for voltage control and reactive power management. For those reasons, the integration of new and improved forecasts for RES generation and load are needed.

The innovation is furthermore reflected in the combined optimization of active and reactive power as it is illustrated in Figure 6. The illustration shows that the active and reactive power provided from the distribution grid to the transmission grid is controlled and jointly optimized in the EU-SysFlex optimisation. Additionally, the project illustrates how the requirements for active and reactive power coming from the transmission grid are followed and how the requirements are broken down for individual plants included in the Demonstrator.

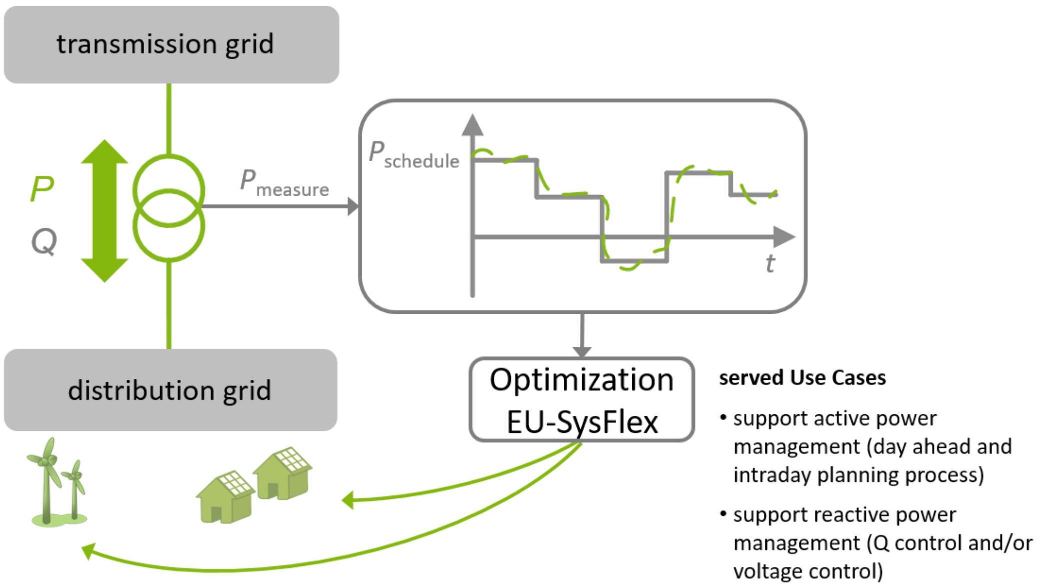

FIGURE 6 - OVERVIEW OF EU-SYSFLEX OPTIMIZATION IN THE GERMAN DEMONSTRATOR (SOURCE: ADAPTED FROM [11])

Innovations in German Demonstrator regarding Active Power Flexibility[2]

The innovation in the German Demonstrator regarding active power management is the cooperation between the TSO and the DSO within the automated process of schedule based congestion management. The innovative process is based on the existing one, using flexibilities of conventional resources in transmission grid, and is being broadened to integrate RES connected to the distribution grid in it. 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 follows:

First, congestions in the distribution grid are managed by the DSO, and then the remaining flexibility potentials of active power are offered to the TSO. The TSO calculates its network and requests the necessary flexibilities from the DSO for the German and the European redispatch process. In case of flexibility requests, the DSO breaks the flexibility call down on individual plants and gives the instructions to the appropriate plants for respective timetable changes. This day-ahead process is illustrated in Figure 7.

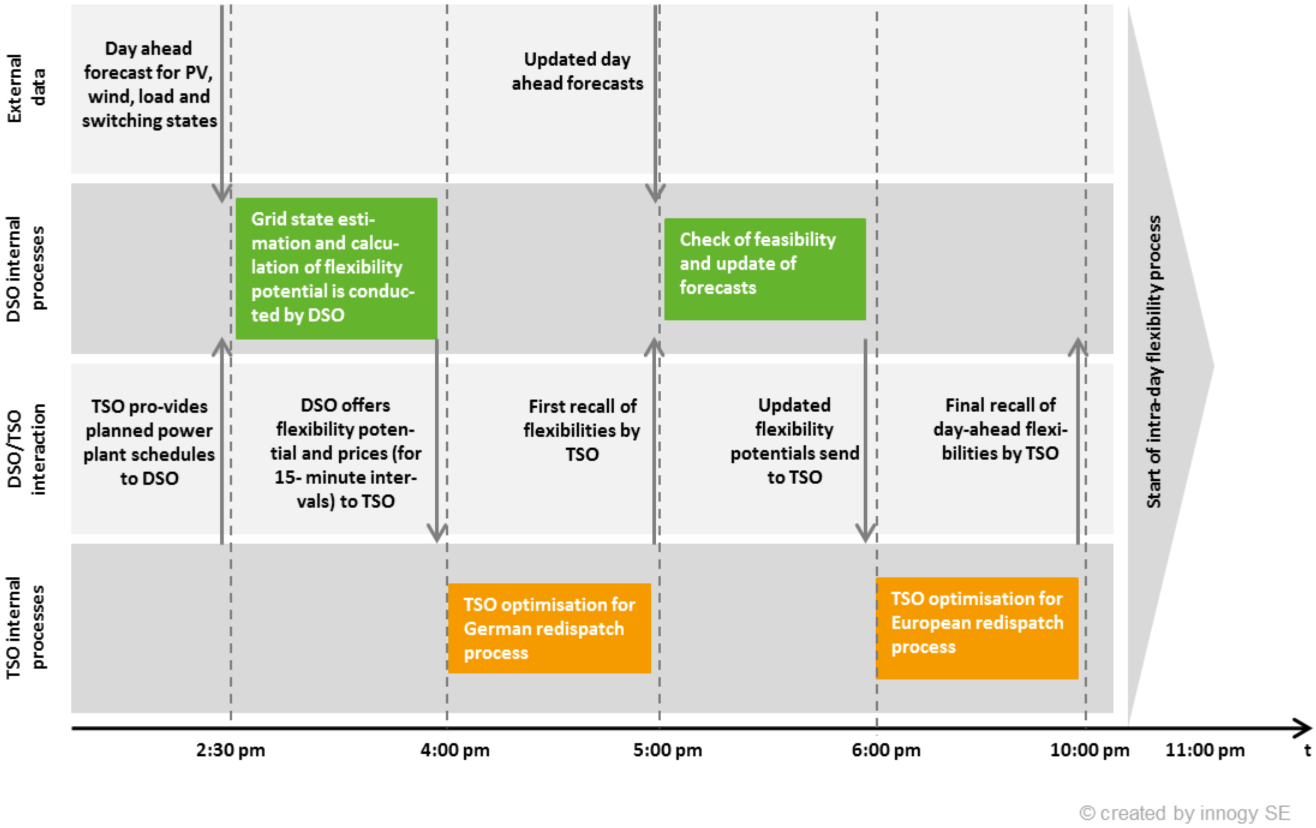

FIGURE 7 - DAY-AHEAD PROCESS FOR ACTIVE POWER FLEXIBILITIES

[2] Currently the legal basis of renewable energy resources participating in the redispatch process is under discussion within the legal amendment of the NABEG (Gesetzes über Maßnahmen zur Beschleunigung des Netzausbaus Elektrizitätsnetze) law [12]. As the results are neither public nor confirmed, this change in law is not detailed within this deliverable even though the results might have an impact on the German Demonstrator.

Due to forecast deviations, a continuous intraday process for active power flexibilities is set up in addition to the described day-ahead process. The intraday process is visualized in Figure 8.

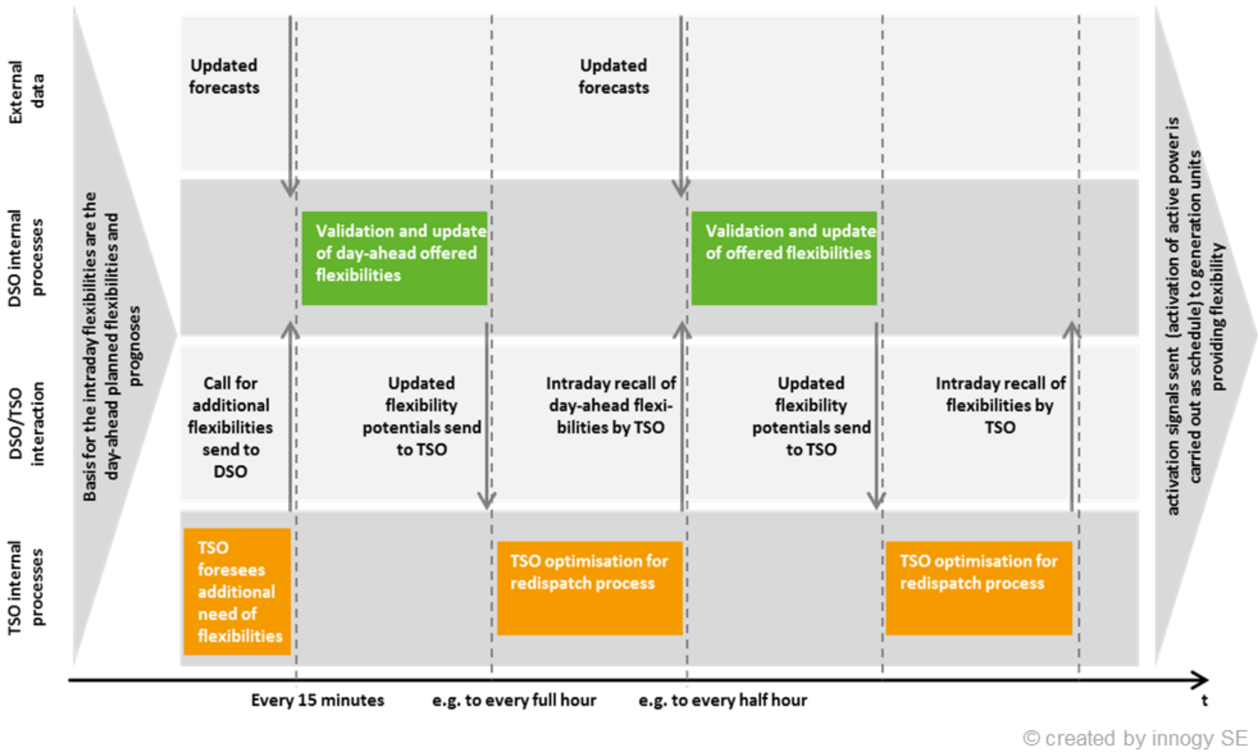

FIGURE 8 - INTRADAY PROCESS FOR ACTIVE POWER FLEXIBILITIES

Innovative character compared to the previous project of PG FHWM

The principle of the EU-SysFlex Demonstrator is the same as one variant defined in PG FHWM - with the difference that it is put into practice in EU-SysFlex. The German Demonstrator therefore builds upon the results from the defined processes of this project group of TSO and DSOs and puts one process into practice to test it. Therefore, the needed functionalities will be defined and developed. The results of the field test will be evaluated to detect further development needed for an automated process.

Innovations in German Demonstrator regarding Reactive Power Flexibility

The innovation in the German demonstrator regarding reactive power management is the set-up of an automated tool for dynamic voltage control and reactive power management. In today's voltage control actions, dynamic local voltage control in the distribution grid is not considered as flexibility for transmission grid. The demonstrator has exactly the goal to show the feasibility of reactive power flexibilities from plants in the distribution grid as a service to the TSO.

For this, the DSO runs a combined optimization for active and reactive power calculating the reactive power potentials, which can be offered to the TSO. As soon as the TSO foresees possible violations of voltage limits, flexibilities from the offered potential can be requested. The process for this is illustrated in Figure 9. The goal is to set up an automated process for this, which will be running in parallel at first, but is built to be running fully automated in the long term.

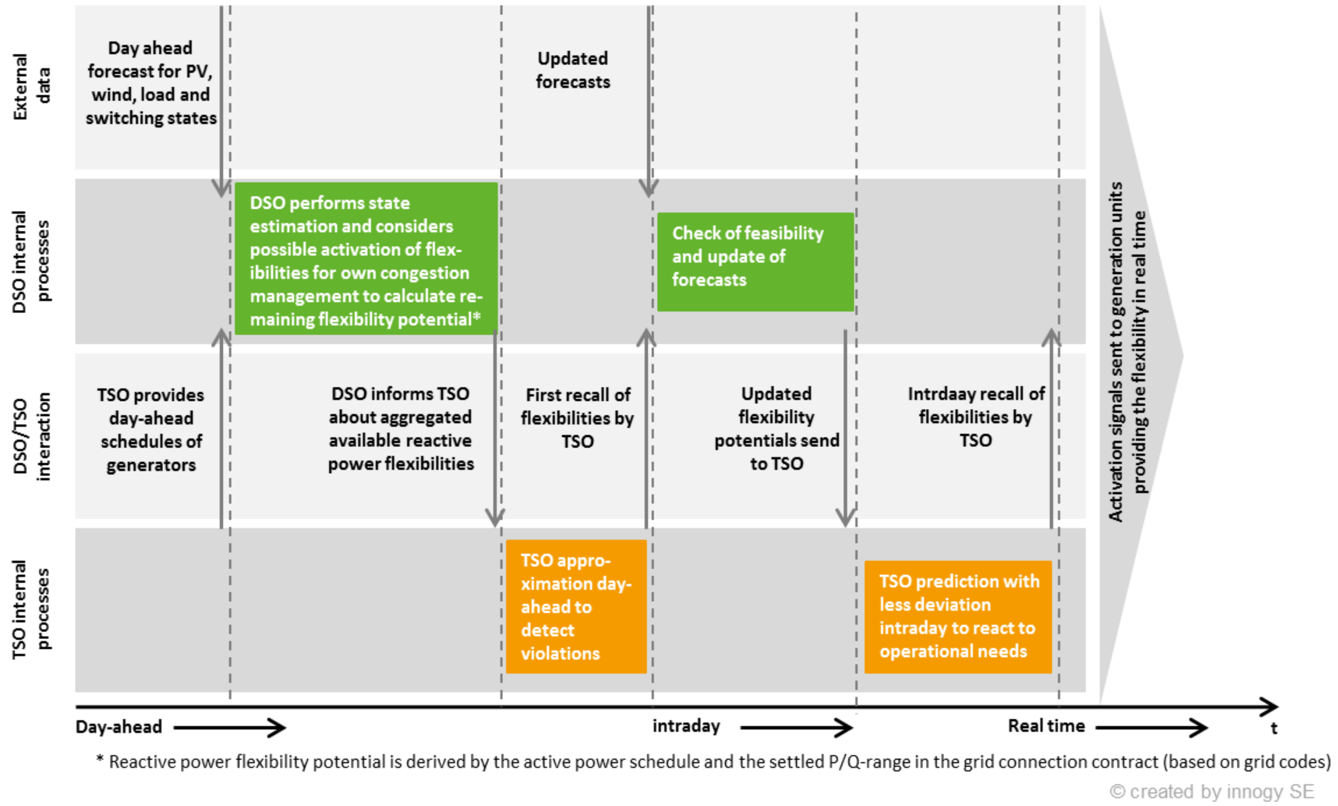

FIGURE 9 - PROCESS FOR REACTIVE POWER FLEXIBILITIES

Innovative character compared to the previous project of SysDL2.0

The main innovation compared to the established tool for reactive power management in the project SysDL2.0 is the full automation and a direct connection to the active control system. In addition, the optimization methods of this tool are newly set up. The goal is furthermore to reduce time needed for the process. In SysDL2.0 the tool is 20 minutes behind the process due to data transferring architectures and a measurement cycle of 15 minutes. The ambition within EU-SysFlex is to reduce the time needed to only 5 minutes behind the process.

Within the tool, a network state estimation and optimization will be conducted every 5 minutes. A link to the active power optimization is planned for joint optimization, which was not considered in SysDL2.0. A connection directly into the control system will be established with visualization. Therefore, the possibility of fully automate this process will be established compared to the previously described manual process of SysDL2.0.

The forecasting window will be extended from 4 to 36 hours and the results will be integrated in a forecast update function. Therefore, an improved quality in forecasting is expected compared to SysDL2.0

The German Demonstrator also analyses and defines the requirements of forecasting to fit in this process. An enhanced forecasting is required to meet the innovations described above. This enhanced forecasting improves the accuracy of forecasting as well as shortens the intervals of updating the forecasting from once a day to once every 15 minutes. This includes both the forecasting of consumption and generation, especially RES generation.

To meet the requirements on forecasting and coordination processes, requirements for data exchange arise. These data exchange requirements for integrating grid data in the forecasting are also part of the focus of the German Demonstrator.

2.6 ENVIRONMENT OF DEMONSTRATOR

Grid structure and location

The German Demonstrator uses flexibilities of generators in the HV grid of MITNETZ STROM for the EHV grid of 50Hertz. Therefore, it is located in the meshed HV grid of MITNETZ STROM in South of Brandenburg and Saxony-Anhalt and in the West and South of Saxony. Figure 10 pictures the location of the German Demonstrator.

FIGURE 10 - LOCATION OF THE GERMAN DEMONSTRATOR

MITNETZ STROM is one of the underlying DSO's of the TSO 50Hertz. MITNETZ STROM supplies 2.3 million inhabitants, in its own grid and in grids of 55 underlying DSOs. MITNETZ STROM alone has over 1.6 million metering points including private customers, trades and industries in an area of nearly 31,000 km² in the east of Germany. In the area of MITNETZ STROM, RES generation covers for 104 % of annual consumption. The installed capacity of RES amounts to 8.7 GW of a total capacity of around 10 GW. This illustrates that a share of about 8 %

of the overall RES capacity of Germany (110 GW) is installed in the area of MITNETZ STROM, but only 4 % of Germany's 80 GW peak consumption accumulates in this area. The peak consumption amounts to less than 3.3 GW in the area of MITNETZ STROM. The HV grid has a length of about 6,000 km and 16 interfaces to 50Hertz as well as 186 interfaces in HV level or as HV/MV interconnection to underlying DSOs. Within the timeframe of EU-SysFlex (2017-2021), at the beginning of the field tests, two more interfaces to 50Hertz will be put in operation. MITNETZ STROM also operates large MV and LV grids with over 67,000 km of length and more than 250 interfaces at these levels to underlying DSOs.

Included Flexibilities

The flexibility resources used in the German Demonstrator are all renewable and conventional resources connected to the 110 kV level, which assembles in total a capacity of 5.2 GW installed generation. In the demonstration, the following installed capacities will therefore be used as flexibility resources:

- 2.7 GW wind power,
- over 1 GW photovoltaic
- and 1.5 GW conventional sources

The resulting potential for reactive power flexibility, which is made useable in German demonstration, assembles to -350 Mvar and +280 Mvar.

The flexibilities and their level of voltage connection are illustrated in Figure 11.

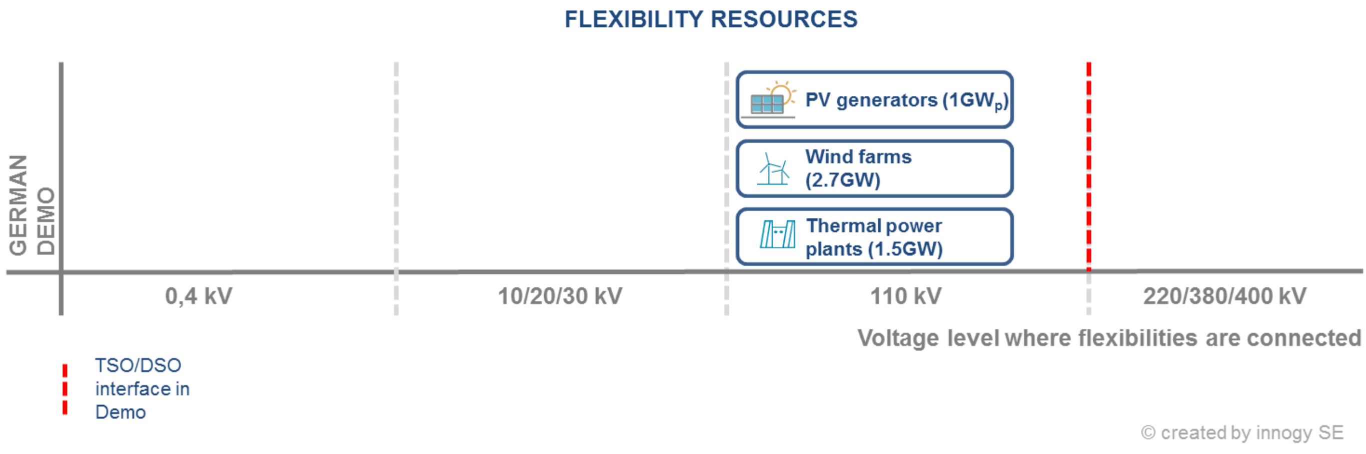

FIGURE 11 - CONNECTION POINT OF FLEXIBILITY RESOURCES IN THE GERMAN DEMONSTRATOR

2.7 TOOLS

For the implementation of the German Demonstrator multiple tools are developed, and explained in this chapter. The majority of the tools is being developed by Fraunhofer IEE in cooperation with University of Kassel and one tool is being developed by INESC TEC.

Grid topology analysis and processing

Based on the grid topology, an analysis and reduction of this topology will be performed. The topology resulting from a grid computation and analysis framework is very detailed and contains beside the region of interest parts from neighbouring grid regions and voltage levels.

In a first step, a topological search is performed, in order to identify all active elements, which are electrically connected with the slack (voltage stabilizing power plant, which is most of the time located in EHV grid). Collecting all connected elements and disregarding all disconnected elements reduces the amount of data, and increases the performance of the following applications.

In a second step, generation and consumption from MV and, if included in the grid topology, LV can be aggregated and projected directly on HV-nodes without influencing the results. In this case, for the project EU-SysFlex, it is useful, since the SCADA of MITNETZ controls reactive power of DER at HV-side of the interconnecting transformers between HV and MV but active power is controlled on MV side. It also further reduces the amount of data, which needs to be processed by further applications, as for example double lines will be aggregated to one.

State Estimation

The state estimation based on the processed topology and a set of measurement values in the CIMDB. Missing and erroneous measurements are replaced and improved.

Congestion Management

The congestion management tool is used to check and solve violations on N-1 contingency on the high voltage grid with the grid configuration and estimated state from the state estimation tool.

The tool checks and solves violations on N-1 criterion, especially the overloading problem on a line after the potential failure of another line. The tool should meet the standard at the grid control centre to guarantee the rightfulness of the result for further optimization of generation set point (especially reactive power set point). In the network congestion management process, the tool checks violations on N-1 criterion and find in-feed curtailment of generation units according to the sensitivity to the congestion point and in-feed priorities defined in the regulations iteratively until the network has no more N-1 violations. The network state with new P-set point will be transferred to the optimization tool.

Forecast Network States

For two time domains, predicted generation and consumption are available. The first domain is the short time forecast, which ranges up to 6 hours ahead; the second domain is the intraday domain, which ranges up to 36 hours ahead.

With those predicted values and the current grid topology, future network states can be generated. For this, the prediction for each generation or consumption node is projected onto the related grid node. There are predictions for every node in the HV grid, which then results in a unique state for a load flow calculation. If additional switching events are available, they are included in the particular grid at the given time stamp. No predictions for EHV nodes are included here, that means that variations taking place in EHV are neglected.

The result is a set of intended network states on which further calculations and optimizations can take place.

Active power loss optimization

The main purpose of this optimization is the reduction of active power losses in the HV grid using the reactive power capability of decentralized power plants directly connected to the HV grid. The optimization considers following network constraints under which the loss minimization takes place. These are:

1. Bus voltage boundaries
2. Line and transformer loading boundaries
3. Active to reactive power ratio in lines and transformers

Active Power Coordination

The objective of the Active Power Coordination tool is to enhance the coordination between TSO and DSO by using active power flexibilities mainly for congestion management. Therefore, the detected available active power flexibilities at TSO/DSO interface need to be sent to the TSO, and requests from the TSO need to be put into the other tools to calculate the remaining active power flexibilities as well as the resulting reactive power flexibilities.

Reactive Power Coordination

The purpose of the Reactive Power Coordination tool is to enhance the coordination between TSO and DSO in using reactive power flexibilities mainly for voltage control. Therefore, the detected available reactive power flexibilities at TSO/DSO interface needs to be sent to the TSO and requests from the TSO needs to be put into the other tools to calculate the resulting available flexibilities in active and reactive power.

PQ-Mapping

The purpose of this tool is the prediction and visualisation of available active and reactive power flexibility potential at the DSO-TSO-interface. This is an alternative to the optimisation and coordination tools developed by Fraunhofer IEE and University of Kassel presented above. It can be seen as a decision-aid tool that intends to support the TSO in performing accurate active and reactive power requests at their interfaces with the DSO (i.e. without jeopardizing the distribution network operation). Therefore, the outcome of this tool can serve as a starting point to other algorithms used in the decision making processes (e.g., definition of the flexibility resources that need to be activated in order to fulfil the TSO requests). It is being developed by INESC TEC and consists on an OPF-based methodology (with an adaptive objective function) that determines the entire range of feasible set-points that can be exchanged at the DSO-TSO connection points while respecting the distribution network constraints (e.g., voltage limits). The innovative aspect of this tool is that it computes an estimation for more than one primary substation at the same time (i.e. meshed grids). To do so, it needs to take into account the existing interdependencies among the several substations. Therefore, an algorithm capable to develop transmission network equivalents is also being developed. This methodology together with the PQ maps will allow to achieve the final goal – estimation of active and reactive power flexibility ranges for more than one single primary substation.

2.8 APPLICABILITY AND LIMITATIONS

Possible Application to different Voltage Levels

The German Demonstrator shows the coordination in using flexibilities from HV grid to EHV grid between TSO and DSO. The designed process is developed in consideration of today's German regulatory framework and operational responsibility of the different voltage levels. Nevertheless, it is designed in a way that adaptions are possible for coordination between MV and HV grid, if this is the interface between the TSO and the DSO. Furthermore, for TSOs operating the HV and EHV level, the process is also feasible internally, in order to integrate plants from the HV grid into the redispatch process.

The coordination process between different TSOs is out of scope. For the German Demonstrator the existing coordination in day-ahead planning remains unchanged.

Limitation due to Regulation

The use of flexibilities in the German Demonstrator is subject to the regulations of RES. The settlement of innovative products cannot be shown unless it fits into today's regulatory framework, but the technical feasibility can be shown. Due to this, the use of flexibilities from RES is settled as curtailment within today's regulations. In contrast to that the demonstrated process to integrate RES is innovative and not the conventional curtailment process, even though it is settled as such.

2.9 EXPECTED RESULTS

The expected outcome of the German Demonstrator is enabling the provision of flexibility services from DSO connected sources to the TSO, for the TSO's congestion management due to line loadings and voltage limit violation.

Figure 12 shows at which voltage level these RES providing flexibility are connected and to where they are offered. It illustrates that in the German Demonstrator flexibility resources from the 110 kV voltage level are offered to the transmission level and are additionally used in the 110 kV level itself.

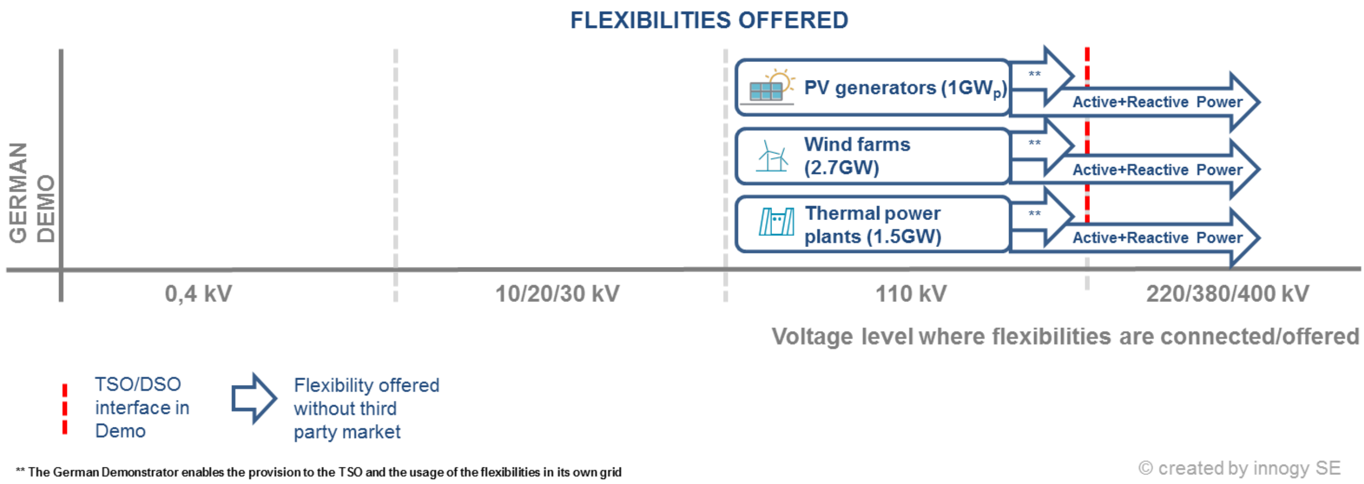

FIGURE 12 - FLEXIBILITIES OFFERED

Figure 13 furthermore displays what scarcities these flexibilities solve. In the German Demonstrator, the flexibilities are used as measures against voltage violations and congestions.

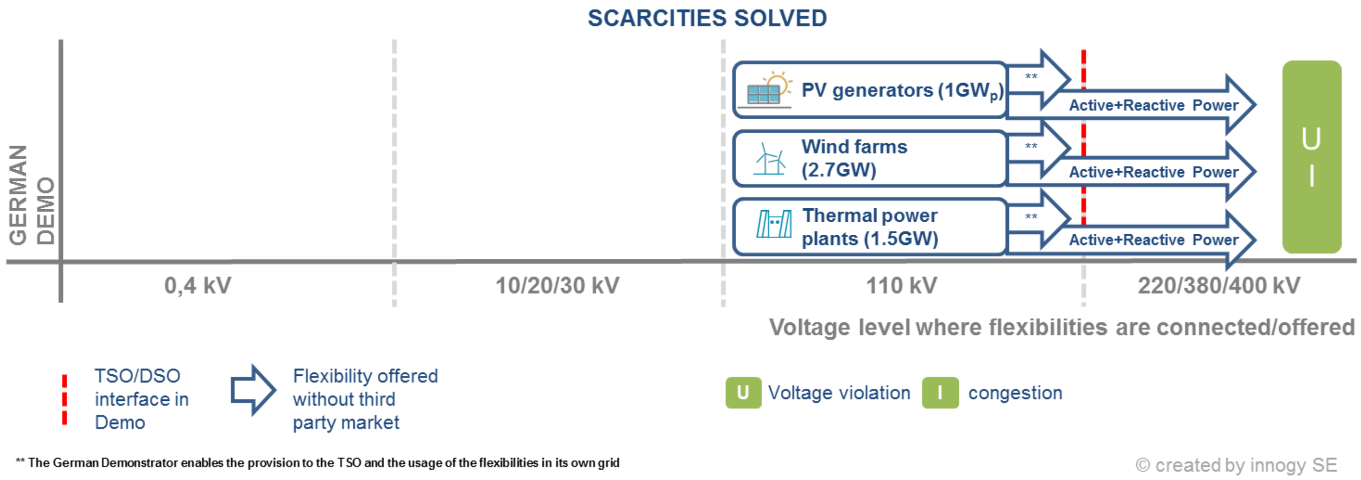

FIGURE 13 - SCARCITIES SOLVED BY FLEXIBILITIES

The German Demonstrator will show a functional verification with real actions in field test for the developed process in active and reactive power management. The foreseen development will result in a prototype status ready to implement in real operating processes. That includes the proof of concept of an efficient process with an increase of flexibilities, which can be used at the transmission grid as well as a loss optimized distribution grid. The increase of the use of flexibilities implies a cost-efficient use of active and reactive power for ensuring the maximum feed-in of RES.

The German Demonstrator will also show the feasibility of a fully automated process of a combined grid optimisation in active and reactive power flow, which is based on an accurate forecasting.

Another expected result of the German Demonstrator will be the proof of concept of the developed coordination process between TSO and DSO for redispatch.

Developing innovative settlement and proof of concept is not an expected result of the German Demonstrator since it is out of scope, whereas pointing out the limitations of today's settlement is within the scope. The same goes for market frameworks for using the flexibilities, because market framework and settlement are mutually dependent.

3. THE ITALIAN DEMONSTRATOR

Overall Objective

To test and validate the provision of ancillary services to the TSO grid by resources connected to the MV DSO network, taking into account TSO and DSO mutual needs and constraints

Status Quo

- *High share of RES in distribution networks, mostly PV;*
- *Scarcity of resources in the transmission network for the provision of ancillary services;*
- *Lack of schemes for the participation of distributed resources to the ancillary services;*
- *Improved MV and LV network automation.*

Drivers

- *Increase in distributed generation;*
- *New rules from the Italian Authority;*
- *Need for a more reliable and resilient distribution network*

Previous Projects

GRID4EU FP7 Project

EU-SysFlex Innovation

- *Including RES, Storage and STATCOM in congestion management, balancing and Voltage support*
- *Set up of new coordinated process for ancillary service provision to the TSO*
- *Automated tools for Network State Analysis, Network Optimization and Reactive Power Management*
- *Integrating improved forecasting for RES generation and load*

Environment

Grid (15kV – 20kV):

- *1 HV/MV Substation*
- *~ 8 MV feeders*
- *~ 260 MV/LV Substations*
- *Installed DER capacity: 39.8 MWp*

Flexibility resources

- *Average energy produced: ~46 GWh/year*
- *Storage System (1 MVA/1 MWh)*
- *4 remote controlled PV generators;*
- *On-Load Tap Changer at HV/MV substation;*
- *2 STATCOMs (1 for each MV busbar)*

Tools

- *Grid topology analysis and processing*
- *State estimation*
- *Forecast network states and generation*
- *Reactive power capability calculation*
- *Network optimization*
- *Flexibility aggregation*

Applicability and Limitations

- *Possible application to different voltage levels*
- *Limitations due to regulation*

Expected Results

- *Proof of concept of coordinated TSO/DSO congestion management*
- *Feasibility of fully automated process of a combined grid optimization (P – simulated – and Q)*
- *More accurate RES feed-in and load forecasting*

3.1 GENERAL OBJECTIVE

Research object

The Italian Demonstrator will explore the evolution of distribution network infrastructure, by integrating the monitoring systems with advanced smart grid devices, for encouraging the ancillary services provision (e.g. voltage control, congestion management, frequency balancing) taking into account both TSO and DSO needs and constraints.

This will be possible due to:

- tools/systems/devices development and integration within the DSO infrastructure;
- the development of new actions needed for a better coordination between the TSO and the DSO;
- the improvement of the real knowledge of the network state and its utilisation, improving the network observability and forecasting systems;
- optimization of the distribution network operations, by exploiting DERs and DSO assets.

Goal of the Demonstrator and expected benefits

In order to reach these objectives, the Italian Demonstrator aims at:

- defining the data exchange between DSO and TSO;
- power modulation at HV/MV substation level for TSO necessity.

The first point will allow a better coordination between DSO and TSO and a better observability from TSO of the power system allowing it a more accurate management of the system. The second point will allow the distributed resources to provide ancillary services to the transmission network. This will not only allow a better management of the transmission network, but also a better management of the distribution network thanks to the advanced controls adopted by the DSO.

3.2 STATUS QUO

The distribution networks in Italy are characterised by a high penetration of RES (about 24 GW of RES connected to the distribution network level in Italy, for about 120GW of total installed electricity production capacity), which can cause voltage control issues and congestions. The simplest solution for the DSO to avoid these effects is the replacement of lines and transformers. However, this solution is not always cost efficient and the implementation of smart grid architectures represents a possible alternative.

For this reason, in the last years, advanced control solutions have started to be adopted for the management of distribution networks, such as in the network considered in the project, where a control architecture is already installed. The adoption of this solution is not only useful for the operation of distribution networks, but also for their coordination with the transmission network. This is particularly important in the present situation where, due to the increasing share of RES and the corresponding decrease in conventional generation capacity, there is a scarcity of resources in transmission network that can provide ancillary services.

This inconvenience is faced by the TSO, which started to install compensator devices (e.g. STATCOM). In addition, in the ancillary services market (MSD in Italy), the TSO requires conventional generators to modify profiles scheduled in previous markets, in order to increase the available flexibility. The modification of the scheduled profile is a costly operation that has to be covered by TSO. The adoption of these actions will be more and more necessary in the future, with the increasing share of distributed generation.

The improvement of the coordination between distribution and transmission allows the distributed resources to participate to the ancillary services, reducing the need of conventional measures.

3.3 INTERNAL AND EXTERNAL DRIVERS

Different drivers, both external and internal, affect the Italian Demonstrator and incentivize the main goal of the EU-SysFlex Project, in the development of new actions needed for a better coordination between the TSO and the DSO. Figure 14 shows an overview on these drivers.

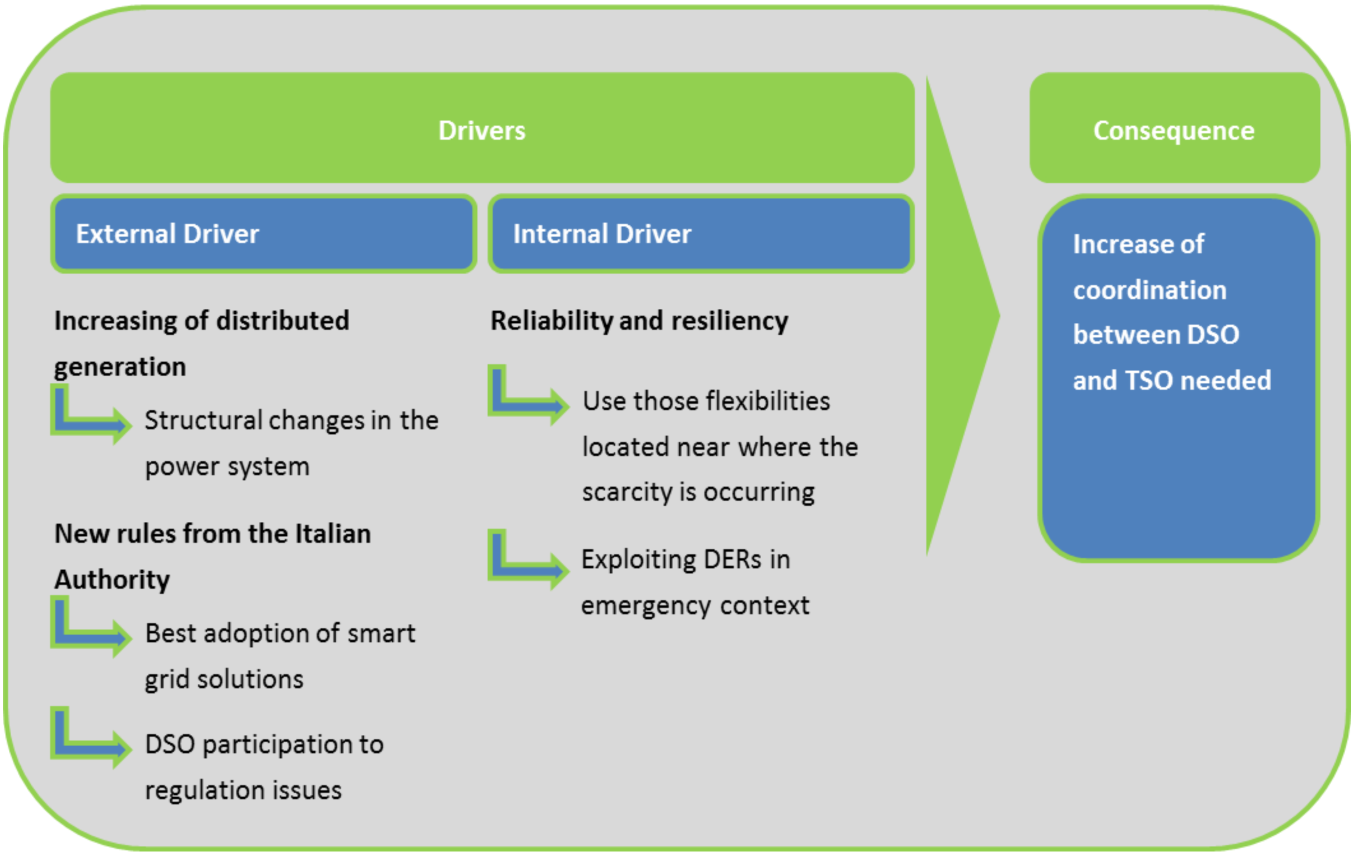

FIGURE 14 - DRIVERS FOR THE ITALIAN DEMONSTRATOR

External Driver: Increasing share of distributed generation

The continuous increase of distributed generation affects directly and indirectly the operation of transmission network. Directly, because the nodes of transmission network, which traditionally behave as loads, now are also injecting power. Indirectly, because the increase of distributed generation reduces the conventional generation directly connected to the transmission network. This evolving scenario is leading to a decrease of the TSO possibilities to regulate the frequency and the voltage within the transmission network and the increase of the probability to have current congestions. These issues have already been encountered in the last years by the Italian TSO (Terna) and the Authority. Terna, in order to avoid congestion and increase the available resources portfolio, planned to add new lines. In particular, new connections are planned between the north, where the load is concentrated, and the south, where the generation is higher, and also to external countries. Besides, it installed some static compensators, in order to better manage the network voltages [7].

The possibility of distributed resources to offer services to the transmission network represent an external challenge (and opportunity) for the DSOs, who have to manage a distribution network where the resources can behave in new and unexpected ways. In this new scenario, DSOs have to facilitate the participation of local resources to different ancillary services to the transmission network. This can be achieved thanks to different functionalities. Firstly, DSOs can help increasing the observability of the power system aggregating the information (e.g. forecast) of the connected resources. Secondly, they can adopt advanced control systems so it is guaranteed that the effects, due to the power modulation of local resource for the ancillary services, do not create problems to the distribution network operations.

As a consequence, DSOs have to study innovative methods, to solve network congestions and voltage violations; nevertheless, an improvement in grid observability and an increase of the Hosting Capacity of the distribution network are needed.

External Driver: New rules from the Italian Authority

The renewable resources have also an impact on distribution networks. They can introduce voltage violations and overloading of lines and transformers. Thus, to improve the operations of distribution networks, the Italian Authority started to incentivize the adoption of smart grid solutions by DSOs [8].

The Italian Authority also acted to support the transmission operation in two ways: for the variable renewable generators connected to the Transmission, it started to align the specifications to the ones of the conventional generators. As for the resources connected to the distribution network (renewable generation, but also conventional, loads and storages), the Italian Authority supported, by means of pilot projects, the possibility of aggregating distributed energy resources to participate in the ancillary service market [9].

For this reason, the DSOs could also use their own assets in order to contribute to the regulation of power flows at DSO/TSO interface. The objective of the project is to show how these functionalities have to be designed and can be implemented taking into account possible technical and regulatory boundaries.

Internal Drivers: Reliability and resiliency

The control of the power flows at DSO/TSO interface could satisfy both the necessity for the TSO to get access to the flexibility of distributed resources and the necessity for the DSOs to operate correctly their networks. Besides, it is expected that in the future, due to the increase of renewables, a higher number of extensive measures are needed for the DSO to better exploit these energy sources, enhancing safety and security issues within distribution system operations.

An internal driver is strongly represented by the real necessity of the DSO to exploit DERs in emergency context. Nowadays DSO has to guarantee service continuity and solving problems related to weather/storm conditions or to multiple outages along both the distribution and the transmission networks. Consequently, it is necessary to promote the study of new scenarios in which DERs are exploited to solve blackouts, enabling the concept of resilient network.

The DSO needs to operate always in security and safety on the distribution network. The new functionalities with the EU-SysFlex project will also contribute to make the distribution network more reliable and safer, enhancing systems monitoring capability and the correct integration between monitoring systems and devices.

3.4 PREVIOUS PROJECTS

The system architecture used in EU-SysFlex comes from the project Grid4EU, where new methods and systems were developed in order to mitigate the problems due to a high share of non-dispatchable distributed generation connected to the MV and LV network. Within the Grid4EU project, a state estimation algorithm and an optimization algorithm were integrated in the SCADA system to test new criteria of voltage regulation by mean of an advanced infrastructure. The infrastructure includes some controllable resources (PV and Storage System), the DSO asset (mainly the OLTC), the ICT infrastructure and the SCADA system itself, able to manage and elaborate all the information. Besides, new criteria of estimation of the residual hosting capacity were developed to optimize the investment.

3.5 EU-SYSFLEX INNOVATION

The innovation of the Italian Demonstrator consists in including RES, Storage and STATCOM in the congestion management, balancing and voltage regulation of both transmission and distribution networks.

From a technical point of view, the most important innovative elements to be developed in the project, improving the results coming from the activities performed within Grid4EU, are listed below:

- The installation of the STATCOM, a new element in the distribution network, the objective of which is the voltage support by reactive power regulation.
- The function of aggregated reactive power capability calculation. This function allows the DSO to determine the reactive power that can be provided by local resources to the TSO.

- An improvement of optimization algorithm that can optimize the network state in order to obtain a desired exchange of active and reactive power at the Primary Substation (HV/MV substation).
- Improved exchange of data between DSO and TSO for a better coordination and a better observability for the TSO of the aggregated flexibility at the primary substation interface.

All the available resources will be involved in voltage regulation services tested in the field, while the integration of RES and Storage for congestion management and frequency balancing for the transmission grid will be, at least, simulated. The voltage regulation will be tested by interfacing RES and DSO resources (Storage, STATCOM and OLTC) with the existing infrastructures, composed by field devices and SCADA system (see Figure 15). Since the challenges posed by the increasing availability of distributed flexible resources are encouraging the evolution of national regulations, it may be the case that, in the near future, such constraints will be dropped, allowing to perform full comprehensive field tests. In particular, the system already carries out automatically network state estimation, optimisation calculations and it sends control commands to the available resources, including the OLTC of the HV/MV transformer. By integrating improved forecasting for RES generation and load, performing the computation of the reactive power capability of each resource and aggregating this information at the Primary Substation interface, the Italian Demonstrator will update these functionalities to set up a new coordinated process with the TSO.

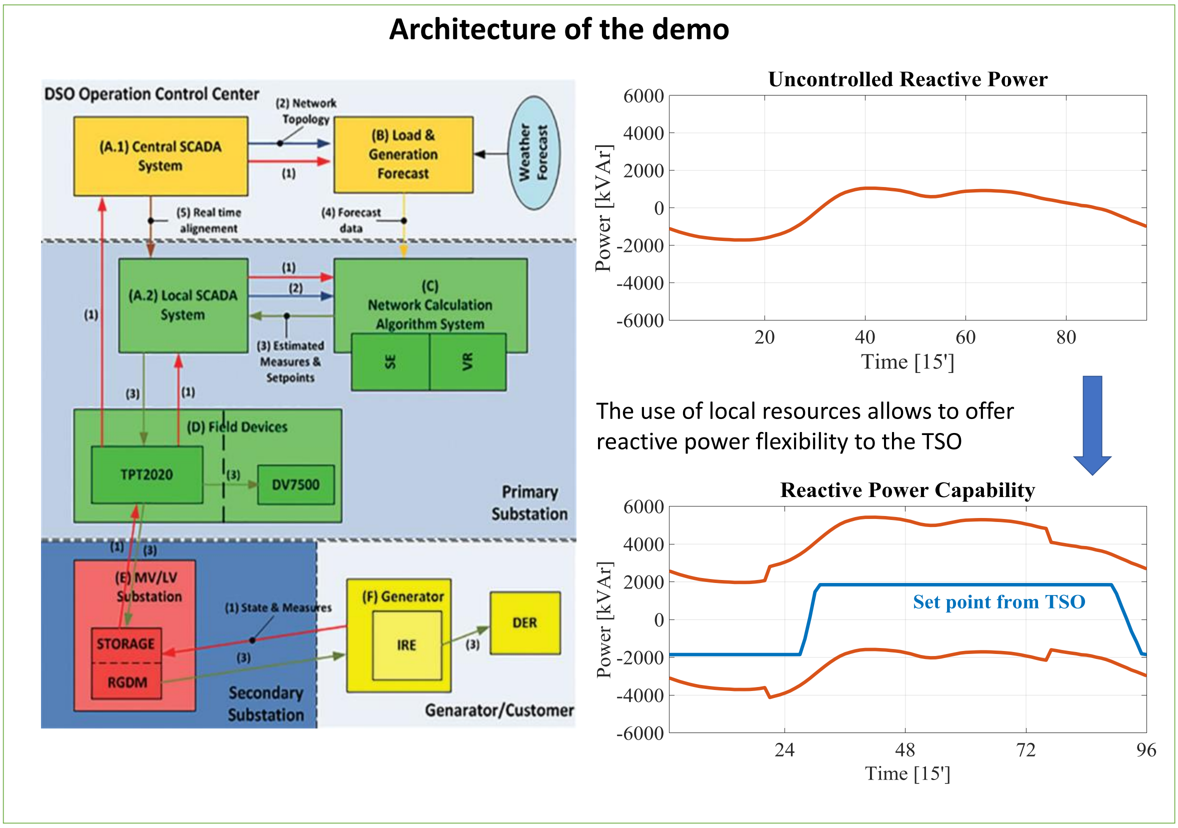

FIGURE 15 – ARCHITECTURE OF THE ITALIAN DEMONSTRATION

3.6 ENVIRONMENT OF DEMONSTRATOR

The demonstration site is located in the area of Forlì-Cesena (Emilia Romagna region).

This area is characterized by a strong penetration of renewable generation (mainly PV), along with low consumption in comparison with the generated energy. The back-feeding phenomena from MV to HV is observed frequently.

The medium voltage distribution network is meshed but radially operated. Each feeder has mostly two or three tie switches normally opened.

The primary substation of Quarto includes two transformers named Red and Green transformers.

The involved portion of distribution network includes (Figure 16):

- 1 HV/MV (132/15 kV) substation and all 8 MV feeders connected to the substation;
- About 260 MV/LV (15/0.4 kV) substations;
- Installed DER Capacity: 39.8 MWp
- Average energy produced per year: ~46 GWh/y.

The involved resources will be (Figure 17):

- 1 Electric Storage System (1 MVA/1 MWh);
- 4 remote controlled PV generators;
- On-Load Tap Changer at HV/MV substation;
- 2 STATCOMs (1 for each MV busbar).

The flexibilities resources of the demonstrator and to which voltage level they are connected are illustrated in Figure 17. In the demo about 2.8 MW of PV generators can provide a controllable reactive power output.

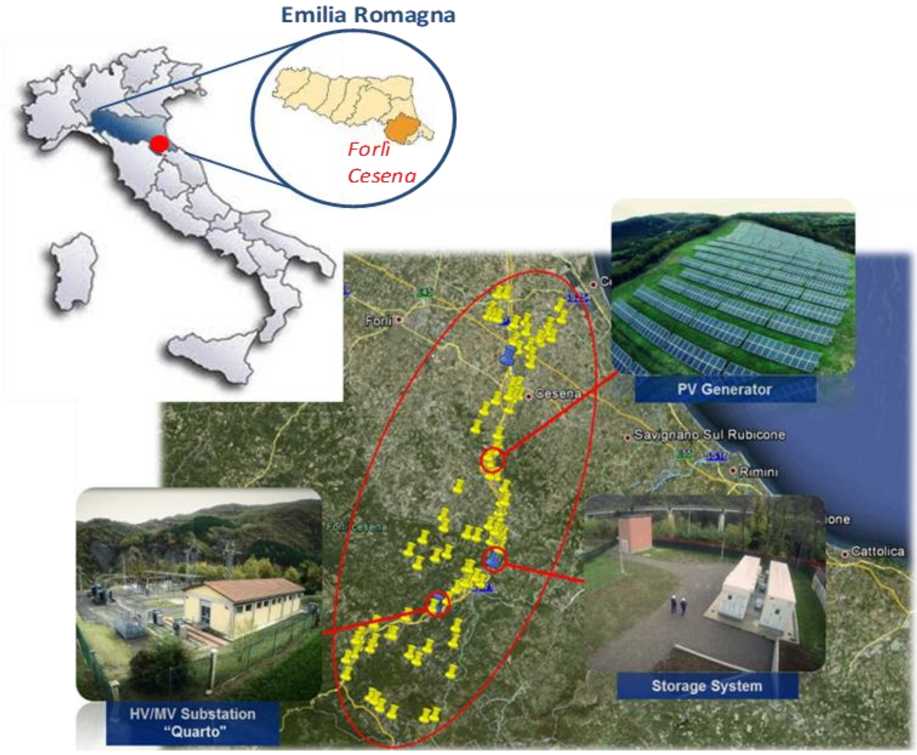

FIGURE 16 - LOCATION OF THE ITALIAN DEMONSTRATOR

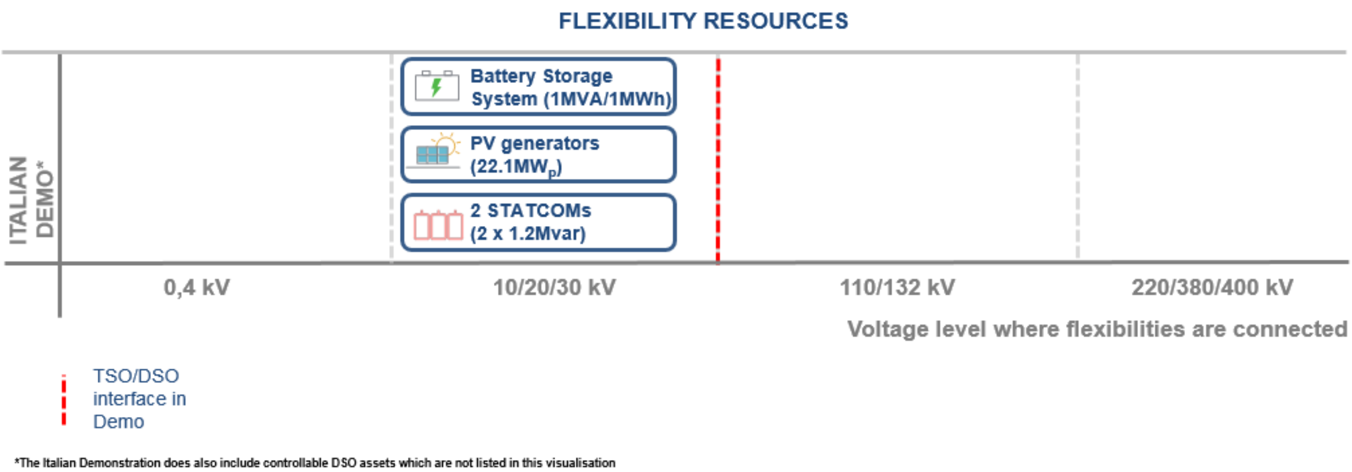

FIGURE 17 - CONNECTION POINT OF FLEXIBILITY RESOURCES IN THE ITALIAN DEMONSTRATOR.

3.7 TOOLS

By integrating the assets listed in the previous paragraph with systems tools, the Italian Demonstrator is capable to process and analyse the grid topology, in order to have a reliable knowledge of the network state, coming from the DSO Central SCADA.

Observability tools

In order to improve this information, the demonstrator already makes use of generation forecasts, updated every hour, and it collects a complete set of measurements coming from the field devices, installed in correspondence of the feeders and some selected secondary substations.

For loads and generators, without forecast information, the state estimation tool (included in Local Scada System located in Primary Substation) takes also into account smart metering data.

These tools provide an accurate observability of the networks and they are therefore a prerequisite for the development of new tools.

Aggregated capability calculation tools

The integration of the state estimator with a network optimization tool, named Vocant, allows to update the reactive power capability for each resource and computes the reactive power capability of the whole distribution network at the Primary Substation. This can be done in different network scenarios, for example including the asset of DSO (e.g. STATCOM) in the reactive power capability. The computation of the capability can be done both with forecast and with real time values. The capability computed with the forecasts allows the DSO to give to the TSO information of the future availability of the network of reactive power flexibility. Instead, the real time values provide the actual capability that the DSO can provide in the very next future. The same approach can be adopted also for computing the aggregated active power capability of the distribution network. This functionality will be tested in real field only in the case that, in the near future, the related constraints provided by the current regulatory framework will be dropped. Anyway, the participation of resources by the modulation of active power, its effects on the network and the advantages of advanced control solution will be surely showed in simulation environment.

Network optimizations tools for respecting TSO request

The same tool described in the previous paragraph can be also used to calculate the optimal set points for each involved regulating resource for two operation modes:

- Normal operation of the system, when no set point from TSO is requested: In this case the optimization, in addition to respect the network constraints, can achieve other goals like the losses reduction;
- Based on a requested reactive or active power profile at the primary substation interface: in this case the set points of the resources are used to reach the desired power at Primary Substation, respecting the

network constraints and satisfying a TSO request. As previously stated, the functionality for the active power management will be evaluated in a simulated environment. In case of evolution of the regulatory framework, the functionality will be also implemented in the field demonstrator.

3.8 REPLICABILITY AND LIMITATIONS

Possible Application to different Voltage Levels

The demonstration is going to be implemented in a distribution network portion that is operated at 15 kV. By collecting previous experience from National and European projects on Smart Grids performed by E-distribuzione, also in areas operated at 20 kV, the concept of the demo can be replicated in distribution networks in which there are different voltage levels and different penetrations of RES.

The demonstration is facilitated by an existing infrastructure, including Intelligent Electronic Devices (IEDs) and SCADA systems, normally used by E-distribuzione, which are going to be improved within the EU-SysFlex project, considering what has been explained in paragraph 3.7.

Limitation due to Regulation

National regulatory frameworks have an impact on the way in which flexibilities are procured and, most important from systems perspective, which system processes are necessary to manage procurement and exploitation of flexibilities.

Actually, in Italy, flexibility provision from private distributed resources is not allowed. The DSO is responsible of the power exchange at interconnection nodes, and so the demonstrator is focused on the improvement/increase of the power regulation window towards TSO. This is done through the optimization of resources for both transmission and distribution networks necessities. From this perspective, the Italian demonstrator considers also the exploitation of DSO-controlled flexibility resources.

The demonstrator considers both active and reactive power modulation and corresponding services. However, some limitations apply on physical set-ups due to regulatory constraints: currently, in the Italian demonstrator, it is not possible to exploit active power flexibilities from private generators. For this reason, the relevant functions, included in the developed System Use Cases and corresponding functionalities, will be included in software tools and these limitations will be taken into account for field test activities. Since the challenges posed by the increasing availability of distributed flexible resources are encouraging the evolution of national regulations, it may be the case that, in the near future, such constraints will be dropped, allowing to perform comprehensive field tests. Anyway, all the relevant functions of the demonstrators will be also tested in a simulation environment, derived from the actual physical set-up.

3.9 EXPECTED RESULTS

What the Italian Demonstrator is going to obtain, as a result, from this project is a proof of concept of an efficient and as far as possible automated coordination process between DSO and TSO.

The forecasting tools should demonstrate that DSO can provide to the TSO a better observability of the resources connected to the distribution network. In particular, the forecast, combined with the network state estimation and the function for the calculation of reactive power capability, should 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 will support also the network state estimation contributing to a better management of the network.

In addition, the results will demonstrate the capability of the DSO to support the TSO requests in both simulated and real field tests.

The demonstration will not only evaluate the effectiveness of the adopted solutions, but the acquired experience will be also be used to improve the operation of the network and to update the SCADA system to be ready for the potential new functionality requested by the regulator.

Eventually, considering that the STATCOM is a new device in E-distribuzione infrastructure, the project represents an occasion to demonstrate that its action is successful, in terms of reactive power capability management. In particular, its operation will provide the following benefits:

- Limitation of reactive power flows at the Primary Substation;
- Meeting TSO requests at TSO/DSO interface;
- Supporting Voltage Control;
- Power factor compensation.

Figure 18 shows at which voltage level the distributed resources providing flexibility are connected and where they are offered to. It illustrates that in the Italian Demonstrator flexibility resources from the 10 to 30 kV voltage level are offered to the transmission level.

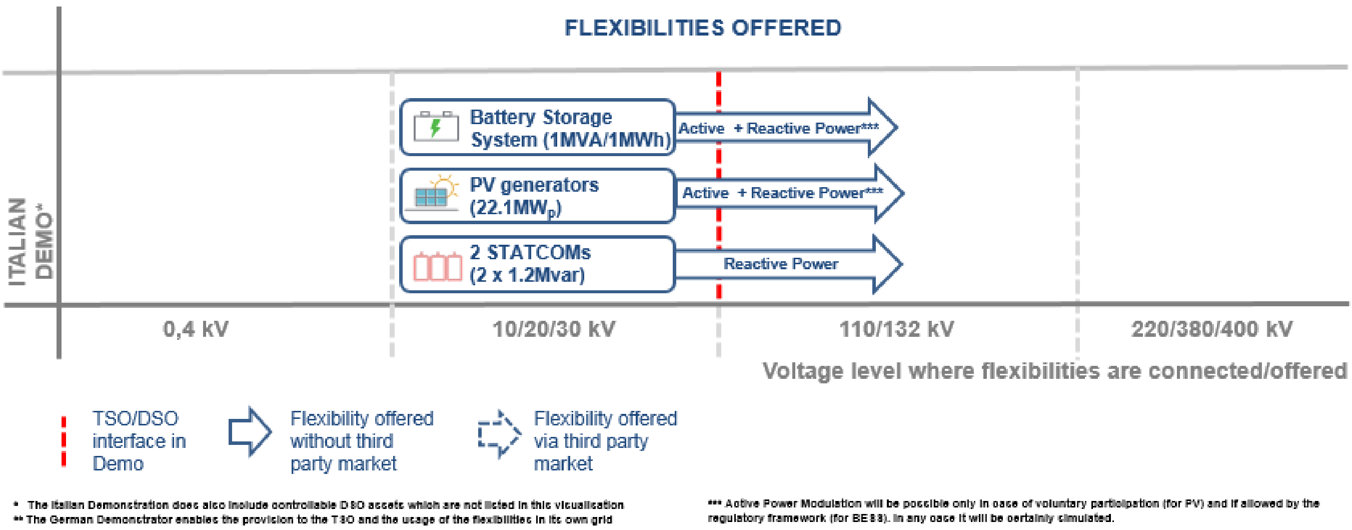

FIGURE 18: FLEXIBILITIES OFFERED IN THE ITALIAN DEMONSTRATOR

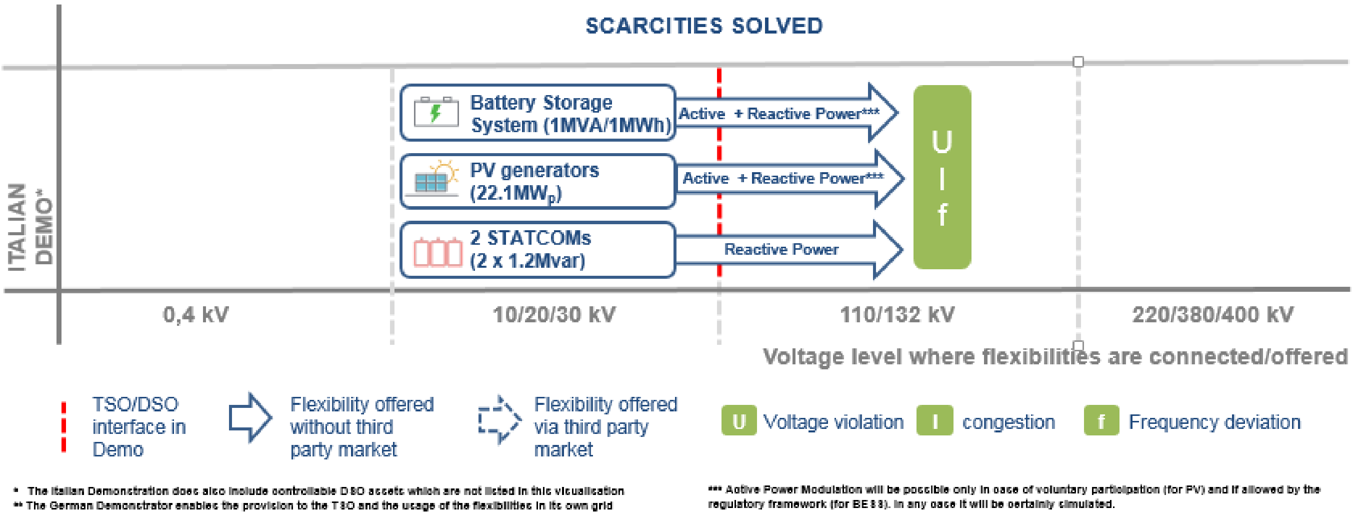

FIGURE 19: SCARCITIES SOLVED BY FLEXIBILITIES IN THE ITALIAN DEMONSTRATOR

Figure 19 furthermore displays what scarcities these flexibilities solve. In the Italian Demonstrator the flexibilities are used as measures against voltage violations, congestions and frequency deviations.

4. THE FINNISH DEMONSTRATOR

Overall Objective

- *Aggregation of flexibilities from distributed assets in the low/medium voltage level for offering them to the TSO and DSO*
- *Set-up of new processes and interfaces for flexibility trading of active power to the TSO and reactive power to the DSO*

Status Quo

- *Increasing share of RES*
- *Lack of possibilities for distributed resources to participate on the ancillary markets*
- *Insufficient flexibility forecasting*

Drivers

- *New business potential for retailers and asset owners arise with the possibility of aggregating flexibilities and offer them in the ancillary service market*
- *Cost-efficiency*

Previous Projects

- *SGEM - Smart Grid and Energy Markets*
- *FLEXe for active power flexibilities*
- *National project for reactive power management*
- *MySmartLife (EU H2020 project)*

EU-SysFlex Innovation

- *Improved forecasting and optimization of available flexibilities of distributed resources*
- *Integration of market mechanisms for reactive power management in the distribution grid*

Environment

Grid:

- *Local DSO with connection points to the TSO (TSO: 400kV, DSO: local 110 kV, 20/10 kV and 0.4 kV)*

Flexibility Assets in Demo:

- *Battery 1.2 MW, 600 kWh (10 kV)*
- *Distributed batteries 24 kW (0.4 kV)*
- *PV power plant 850 kW_p (20 kV)*
- *Residential heating loads 20 MW (0.4 kV)*
- *EV charging stations 3 MW (0.4 kV)*

Tools

- *Forecasting tools*
- *Reactive power market mechanisms (proof of concept)*
- *Reactive power dispatch tool*
- *Aggregation platform*

Applicability and Limitations

- *Limited amount of distributed resources, e.g. EV charging stations*
- *Limitations due to regulation*

Expected Results

- *Demonstrate the aggregation of distributed assets to various TSO's ancillary market and DSO's reactive power needs*
- *The developed forecasting tool estimates the available capacity to be traded to the ancillary services*
- *Increase reactive power capabilities for DSO's purposes*
- *Proof of concept for reactive power market*

4.1 GENERAL OBJECTIVE

Research objective

The general objective of the Finnish demonstrator is to show how flexibility resources, i.e. small, distributed resources, such as electric vehicle (EV) charging stations large scale battery energy storage system (BESS), customer-scale batteries,, PV plant and residential heating loads, that are connected to the low or medium voltage distribution network can be aggregated to be traded on existing TSO market places and/or for DSO's reactive power compensation needs. Figure 20 below presents an overview of the Finnish demonstrator, where the retailer is Helen, the DSO Helen Electricity Network and the TSO in Finland is Fingrid.

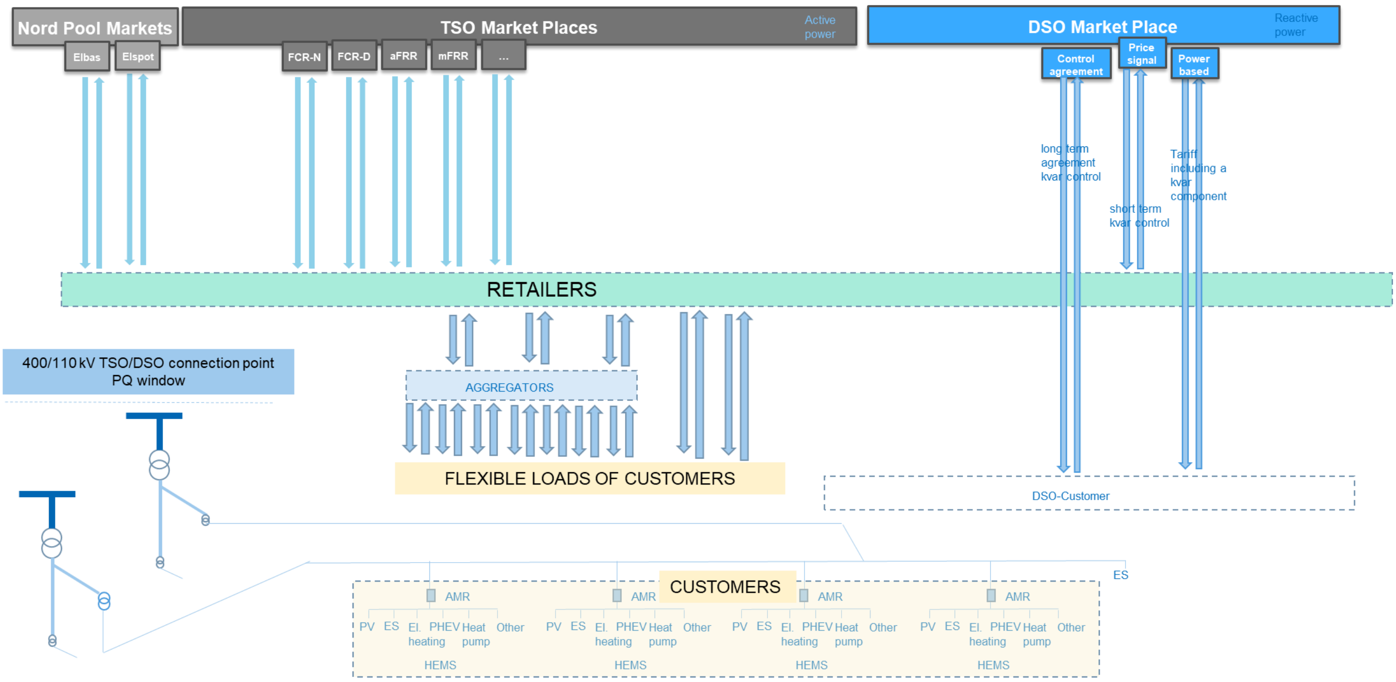

FIGURE 20 - OVERVIEW OF THE FINNISH DEMONSTRATOR.

Goal of the Demonstrator and Expected Benefits

In Finland, the provision of ancillary services to the TSO is completely market-based, which means that the market prices of services are on the one hand, determined by the demand for services by the TSO and on the other hand, by the supply of services and the price at which these are offered. Today, the assets participating in the markets are typically industrial-sized loads or generation connected to the medium voltage (20/10 kV) or to the transmission grid. The size of these assets is in the multi-megawatt scale. This demonstration brings small-scale loads and generation assets connected to the low or medium voltage level to the markets. The size of these smaller assets cover a range of some dozen to hundreds of kilowatts. 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 ultimate goal of the demonstration parties is to ensure the maximal utilisation of RES by increasing the market-driven flexibility of the electricity system. This is achieved by creating a wide mix of resources that are able to participate in the markets. The assets which will be used in the end, depend on the price competition on the market (market-driven). The assets offering their flexibility at the most competitive price will be utilized.

DSOs support the TSO operation of the transmission grid by providing reactive power at the TSO/DSO interface (within the Finnish demonstrator 400/110 kV) to keep the voltage in its defined boundaries. PQ-windows set by the TSO determine the limits for reactive power flow through the window. The PQ-window exists in the TSO/DSO interface. In Helsinki, there are three connection points between TSO and DSO but only one PQ-window. In the PQ-window, the reactive and active power flows in the three connection points are taken into account as a net sum. If the PQ-window limits are exceeded, penalty payments come into force. The DSO therefore conducts reactive power management to fulfil this requirement. The demonstration increases reactive power compensation capabilities for DSO's purposes through a reactive power market. The demonstration will show that distributed resources enlarge the potential flexibilities of reactive power as there is a growing need for more flexible control mechanisms. Therefore, this demonstration aims at proving the concept of utilising small, distributed assets in the low and medium voltage network for ensuring the reactive power provision both at the TSO/DSO interconnection point and locally in the distribution network.

The benefits of the demonstrator can be summarized as follows: The TSO is able to tackle its' need for increased flexibility cost-efficiently with new kinds of distributed assets. This is achieved through aggregators, who bring these assets to the markets and in turn, receive a financial benefit through remuneration. The DSO has more active measures to manage the reactive power through distributed resources and stay within the limits of the PQ-window set by the TSO.

4.2 STATUS QUO

This chapter describes the current situation and environment of the demonstrator in the light of the operation of the TSO, the DSO, TSO ancillary markets, and the PQ-window operation between the TSO and DSO.

TSO ancillary services

The prerequisites for an asset to participate in the reserves and balancing power markets include technical requirements (e.g. minimum size, activation time), market place requirements (e.g. regarding balance settlement) and the passing of a prequalification test. An aggregator can aggregate multiple assets, which do not fulfil the technical and market requirements standalone, into an entity that is qualified to participate on the markets. With the growing share of distributed small scale generation in the Nordic power system, these distributed small scale resources are needed increasingly for the ancillary services to ensure the required flexibility. Typically the assets participating in the markets are industrial-sized loads or generation capacities that are traded by the asset operator or by a retailer. Nowadays, the smallest assets working in the markets are in the size of megawatts and in the demonstration the sizes are some tens up to several hundred kilowatts.

In this demonstration, the distributed assets are traded on existing market places of the Finnish TSO Fingrid. The markets to be considered are currently frequency containment reserve for normal operation (FCR-N), frequency containment reserve for disturbance operation (FCR-D) and manual balancing power market/manual frequency restoration reserve (mFRR). A concept of a market place for reactive power (see next paragraph) is also demonstrated.

PQ-window at the TSO/DSO interface

To support the TSO's operation of the national transmission grid, every DSO manages the PQ-window at the TSO/DSO interface (within the Finnish demonstrator 400/110 kV). The TSO has set the PQ-windows to avoid excessive reactive power input/output between the TSO and the DSOs. The reason for PQ-window is to reduce the voltage violations in the TSO grid due to reactive power inputs/outputs. The DSO is connected to the TSOs network through a PQ-window that the DSO actively controls. If the reactive power exceeds the window limits determined by the TSO, a penalty tariff is charged from the DSO. Currently in Helsinki, the controlling of the PQ-window is mainly realised by a 110 kV reactor and the on/off control of 110 kV capacitors. In addition, a tariff structure also exists between DSO and power tariff customers in order to direct and guide these bigger customers in their electricity usage of reactive power. In real life, the benefits of the tariffs between the DSO and bigger customers have remained minor because the costs of reactive power have so far remained low. Furthermore, no major problems have been caused to the DSO. However, DSOs could use other active methods to reach more reactive power compensation to manage and control the PQ-window at the TSO/DSO interface. Flexible resources regarding reactive power exist in the distribution network but DSOs have no convenient mechanism to reach these assets. It should be noted that the use of reactive power assets connected in the distribution network always need the DSO's validation before working on the market.

Distributed assets

During the past decade Helen has been developing capabilities to integrate third party owned assets into the balancing markets. So far, these assets have typically been industrial-sized loads or large generation capacities. In EU-SysFlex, Helen is aiming at utilising the experience gained with the larger assets to harness small distributed assets to the markets. In Finland, the number of distributed assets is increasing, e.g. alone last year the number of public EV charging stations doubled from ca. 300 to 600 stations [16]. The overall potential for flexibility is coming from residential consumption, mainly in the form of electric heating sources. It has been estimated to be at least 1 GWh/h [17].

The main difference with small assets compared with assets that are already aggregated and traded today is the even higher uncertainty of the available capacity. This demonstration provides solutions to this challenge by developing a capacity forecasting tool of different assets for day-ahead and intraday markets.

4.3 INTERNAL AND EXTERNAL DRIVERS

Different drivers, both external and internal, affect the Finnish Demonstrator: external drivers with the goal to integrate a higher share of RES in the system and internal drivers in the form of improved cost efficiency for the system overall and of increased revenue for the aggregator. Figure 21 shows an overview on these drivers.

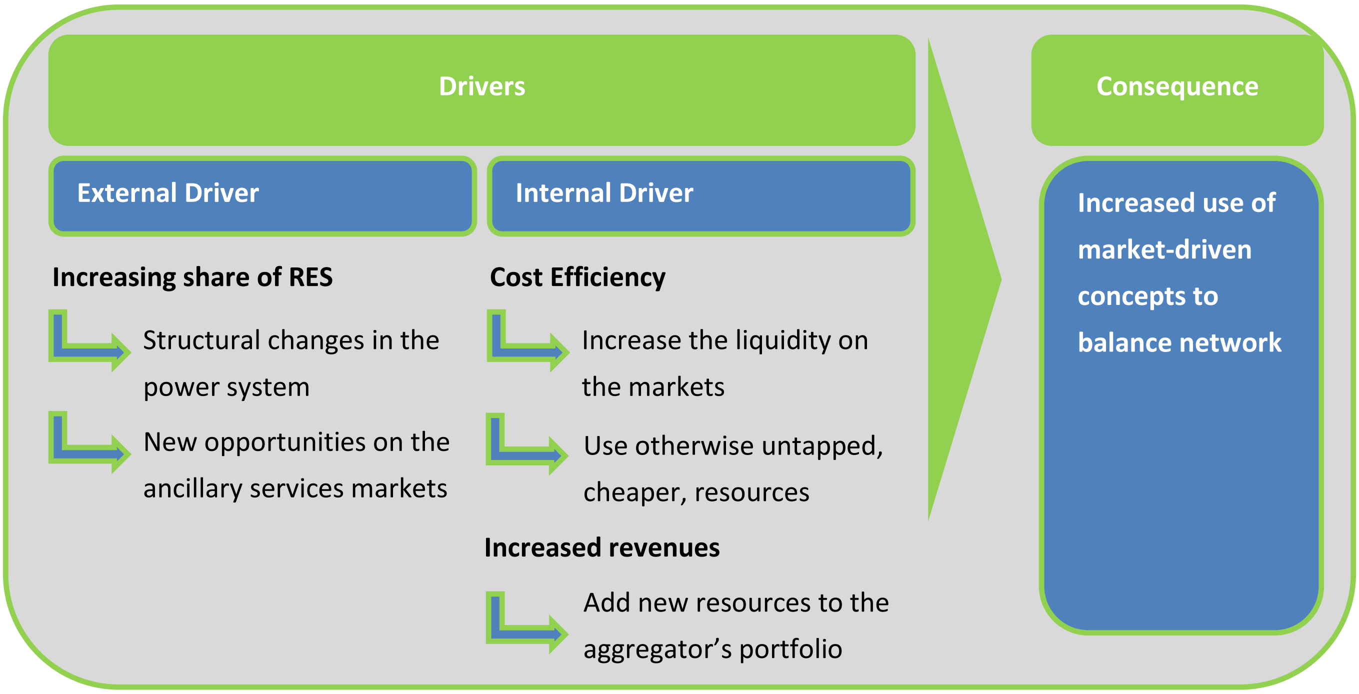

FIGURE 21 - DRIVERS FOR THE FINNISH DEMONSTRATOR

External driver: Increasing share of Renewable Energy Sources

Within EU-Sysflex, deliverable D2.1 “State-of-the-Art Literature Review of System Scarcities at High Levels of Renewable Generation” [1] defines the future system needs. For example, the increasing amount of RES challenges the quality of frequency. The European Commission’s reference scenario [18] mentions a minimum of 26% of the total production by 2020 and 43% by 2030. The EU-SysFlex scenarios, Energy Transition and Renewable Ambition, developed in D2.2 “EU-SysFlex Scenarios and Network Sensitivities” [1] define the demand and generation portfolios for 2030 and 2050. The Energy Transition Scenario has a percentage of electricity from renewable energy sources with respect to overall demand of 52%, while the Renewable Ambition Scenario has a percentage of 66%. Although a good share of RES is based on hydro power, the shares for wind and solar are currently increasing. For example in Finland, the annual electricity consumption in 2018 was approx. 87 TWh, of which 7% was covered with wind power and 0.2% with solar power while the share of wind power in 2014 was only of 1.3%. [13][14]

Frequency control is operated market-based within the TSO’s market places. To respond to the intermittent production, more flexibilities with fast response times should be harnessed on the load side.

By enabling the participation of new flexibilities from the low/medium voltage level to the markets, the liquidity on the markets, i.e. the amount of bids increases, and this leads to the reduction of prices and increased overall welfare. This is favourable on a system level and for the TSO. From the perspective of the conventional resource providers however, this could ultimately pose a challenge, since their revenue is decreased due to the price reductions. In a well-functioning market environment, the regulator or market operator should follow this progression and modify the remuneration mechanisms in order to ensure that the services can still be offered in an optimal way (for example by setting up a remuneration mechanism that is more capacity based and less dependent on the energy provided).

Internal driver: Cost efficiency

The utilization of distributed assets in the low/medium voltage network for stabilisation of the high voltage network benefits all parties below.

- The asset owners and aggregators can increase their revenues by optimising the utilisation of the distributed assets.
- TSO gets more flexibility for balancing the national transmission grid cost efficiently
- DSO gets access through market-based mechanism to flexible reactive power assets in the distribution network and the DSO can control the PQ-window more flexibly

Internal driver: Increased revenue for the aggregator

By varying and increasing the number of assets, the aggregator can operate on different markets and also reduce the risks linked to errors in forecasts. In addition, if the new assets can provide the same services for cheaper than the market price, it results in a direct increase in revenue.

Another important aspect for the aggregator is its image. The aggregator can use the fact that contracting customers and making the resources available can help the system and especially the integration of RES. This could result in securing customers that would otherwise go for another aggregator or retailer.

Consequence: Increased use of market-driven concepts to balance network

Summarized, the main internal and external drivers considered in the Finnish Demonstrator are increasing share of renewable energy sources, cost-efficiency, more possibilities for a DSO to control reactive power (market-based concept), and the increased revenue for the aggregator as new resources are added to the aggregator's portfolio. Consequently, small distributed assets connected to the LV or MV network could be utilized in the TSO ancillary services and for the DSO's reactive power compensation needs through a market-based framework.

4.4 PREVIOUS PROJECTS

In this chapter, the relevant previous projects are introduced. These projects include SGEM and FlexE, which studied the smart grids and energy markets, BESS project, reactive power balance project and EU-funded H2020 mySMARTLife project. SGEM and FlexE introduced the aggregation platform environment. The BESS project tested the technical feasibility of an industrial sized BESS to operate in the TSO ancillary markets and simultaneously offer reactive power to the DSO. At the commissioning time of the Suvilahti BESS in 2016, it was the largest industrial sized BESS in the Nordic countries. During the reactive power balance project, the changes in the reactive power behaviour and the need for additional reactive power management were identified. In the mySMARTLife project, the reactive power compensation capability of Kivikko PV plant was tested.

Projects: SGEM and FlexE

In Finland, wide national research programs dealing with smart grids and energy markets were carried out in two research programs, SGEM (Smart Grids and Energy Markets) 2009 – 2014 and FlexE (Flexible Energy markets) 2015–2016. In these multidisciplinary future energy system projects, models for future energy markets were advanced in addition to technology issues including architecture, management, components and maintenance of grids business. The project combined smartness, flexibility, environmental performance and economic success with customer acceptance and engagement. During these research years, dramatic changes occurred especially in energy production and moreover in consumption and electricity markets. To answer to the arisen challenges the flexibility of the power system had to be strengthened including the electricity markets.

As a project partner of SGEM and FlexE, Helen built smart-grid operational capability by interfacing SIEMENS distributed energy management system (DEMS) with existing energy trading systems and generation SCADA. As relevant results, the capability of the system and external distributed asset interfaces based on IEC protocol and secure VPN tunnelling were constructed, tested and operated. The aggregation and trading of external assets to TSO markets in Finland is now running and further under research and development. In the EU-SysFlex project, the capabilities developed in these two projects are utilised to further develop market-driven smart-grid concepts.

Additionally in the scope of SGEM and FlexE research programs, a novel application for AMR meters, was developed. In that application, residential electric storage heating loads were controlled via AMR meters according to the heating demand and Nord Pool spot prices. In Finland, the AMR metering is DSO's responsibility. Finland is a forerunner in large-scale AMR roll-out, not only in coverage of installations but also in functionality and utilization of the AMR system in various business processes. Since the end of 2013, the Finnish law stated that every customer should have a remotely read hourly measuring AMR meter and they shall have access to own consumption data. The AMR data is utilized in the electricity markets, e.g. for balance settlements. In SGEM and FlexE projects, Helen Electricity Network developed the utilization of AMR metering data in planning, operation, demand side management and development of power-based tariff structures. One successful result was the control of the load of electric storage heating based on electricity market spot price and temperature by AMR meters. Another focused research area of Helen Electricity Network in these flexibility projects was the development of self-healing distribution networks including measures of distribution automation and compensation of medium voltage networks. The aim was to limit the time and affected area of faults (earth faults or short circuits). Then in a case of a distribution network fault, a customer will not experience any interruption at all or the interruption time is dramatically shortened. As a result of this work the supply reliability indexes in Helsinki are now globally in the top class. In Helsinki, the system average interruption index has drastically lowered during the last decade from approx. 6 minutes to 2-3 minutes. As a relevant result, this development has strengthened the customer engagement and widened the DSO's network measurements and automation towards the low voltage network and customer connection points.

Project BESS

One new flexibility resource in a future power system is the battery energy storage system (BESS). The Finnish EU - SysFlex demonstration assets include one industrial scale BESS (1.2 MW, 600 kWh, connected to the 10 kV level). A three year research program has been going on since 2016. The storage is used as a research platform by Helen (energy retailer and producer), Fingrid (TSO), and Helen Electricity Network (DSO). The main objective of the research is testing multiple services applicable to manifold beneficiaries. As a relevant result, this research complements the objectives of EU-SysFlex project as the performed tests raise the feasibility and operational knowledge of this flexible asset.

Project Reactive power balance

Reactive power balance was researched in a national research project, that was financed by Sähkötekniikan tutkimuspooli and conducted in 2017. Helen Electricity Network was participating in this project. As a relevant result of this research, the summary of the voltage and reactive power control in the Finnish power system was modelled and reported.

mySMARTLife

In the EU Horizon 2020 project mySMARTLife assets to perform demand response were built, e.g. the vehicle-to-grid charger in Suvilahti. Furthermore, a technical feasibility study was performed at Kivikko PV plant utilizing the solar inverters of the solar power plant to compensate reactive power. In addition, the first pilot with demand response with customer's asset was demonstrated with one customer scale battery, which is functioning in multi-use to both support local optimization and participating in ancillary services in agreed times.

4.5 EU-SYSFLEX INNOVATION

Based on all the named previous projects, this demonstration takes a step forward by aggregating small, distributed resources to benefit the needs of higher voltage networks (DSO and TSO voltage levels). Until now, these smaller resources have not been utilized in those applications that are to be innovatively demonstrated within the EU-SysFlex project. Active as well as reactive power of the smaller assets are utilized by the demonstrator in the EU-SysFlex research program.

Innovations in Finnish Demonstrator regarding Active Power Flexibility

The active power of the resources is applicable for TSO's frequency and balancing markets. To achieve this, a vital element of the project is to develop a tool that can forecast the availability of capacity from different resources (EV charging stations, residential heating loads, BESS, customer-scale storages) that are characterised by intermittency and variability. Another vital aspect is to demonstrate the data management through the whole value chain, not only regarding the market parties but also external data providers. As some of the distributed resources are typically owned by third parties (e.g. customer-scale batteries), this demonstrator also develops new cooperation between a retailer and the asset owners.

Innovative character compared to the previous projects

The previous projects "SGEM" and "FlexE" form a good starting point for this EU-SysFlex demonstration. In those projects, energy retailer's distributed energy management system was linked with existing energy trading systems and generation SCADA. This was the start for the aggregation and trading of external assets to TSO markets. Furthermore, in the same projects, I AMR heating loads were controlled according to the day ahead spot markets. Now in EU-SysFlex, the capability of these assets and AMR meters' communication systems to participate in the TSO's balancing market is evaluated. In TSO's balancing markets, time requirements are essentially more demanding and new development steps would be needed.

In addition, the "Project BESS", has been a research where the technical feasibility of a battery energy storage system has been diversely tested to study the applicability of such an asset in the sense of the requirements of TSO's frequency markets. In the EU-SysFlex project, the BESS will be introduced as an asset in the real market environment (FCR-N) for commercial use as a part of the retailer's value chain.

Innovations in Finnish Demonstrator regarding reactive power flexibility

Regarding reactive power, so far, the DSO has not utilized third party owned assets. In this demonstration, a market model is presented, which supports the DSO in managing the PQ balance also by smaller reactive power resources.

Innovative character compared to the previous projects

For reactive power, the former research "Project Reactive power balance" reported the drastically changed reactive power balance in Finland that has also been measured and observed by the Finnish demonstrator Helen Electricity Network, the Finnish TSO Fingrid and extensively in Finland. There is going on an apparent and remarkable change in the reactive power characteristic in the Finnish power system. New manners for reactive power management are needed. In the EU-SysFlex project, a novel approach will be tested. Additionally, the other former project “Project BESS” has offered valuable test results how the active and the reactive power of the BESS can be simultaneously utilized for the TSO’s and the DSO’s needs. Battery energy storage systems represent a new kind of asset to be utilized also for the reactive power. Another reactive power asset is a PV plant. The preliminary tests has been run under the project “mySMARTLife” and this controllable resource will be further utilized within the entity of EU-SysFlex.

4.6 ENVIRONMENT OF DEMONSTRATOR

This chapter describes the environment of the Finnish demonstrator. At first, the actors of the Finnish demonstrator are presented. These include Helen (retailer/aggregator), Fingrid (TSO), and Helen Electricity Network (DSO in Helsinki). After this, the assets of the demonstrator are introduced.

Helen Ltd.

Helen Ltd. is the energy company operating in Helsinki, the capital of Finland. Helen generates electricity, district heating and cooling for its over 400 000 customers and actively develops and brings to market new energy-related innovative services for customers. The maximum electricity production in the Helsinki area is ca. 1100 MW. There are no wind power parks in the capital. However, the PVs are increasingly popular. Helen has two bigger PV power plants. The Suvilahti PV plant with a capacity of 340 kW_p was installed and put in operation in 2015 and the Kivikko PV power plant with 850 kW_p in 2016. In addition, small scale PV production is increasing in the city area. However, the share of all PV production in Helsinki is still low (< 0,3 ‰ of the annual consumed electrical energy). Helen has its own electricity production and additionally, the company acquires electricity through ownership of other electricity producing companies. Helen as a retailer and aggregator of electricity offers flexible resources and operates with them at TSO’s markets

Fingrid

Fingrid is the TSO in Finland and a part of the Nordic electricity system and the European electricity markets. Fingrid is responsible for the Finnish transmission grid performing the tasks of electricity transmission, balance services (frequency services and clarification of market clearing afterwards), guarantee-of-origin certificates, electricity market information and information exchange in the retail (whole sale) markets. Through TSO ancillary regulating power and reserve markets Fingrid has more flexibility for the national transmission grid’s operation cost efficiently. The electricity market structure in Finland is illustrated in Figure 22.

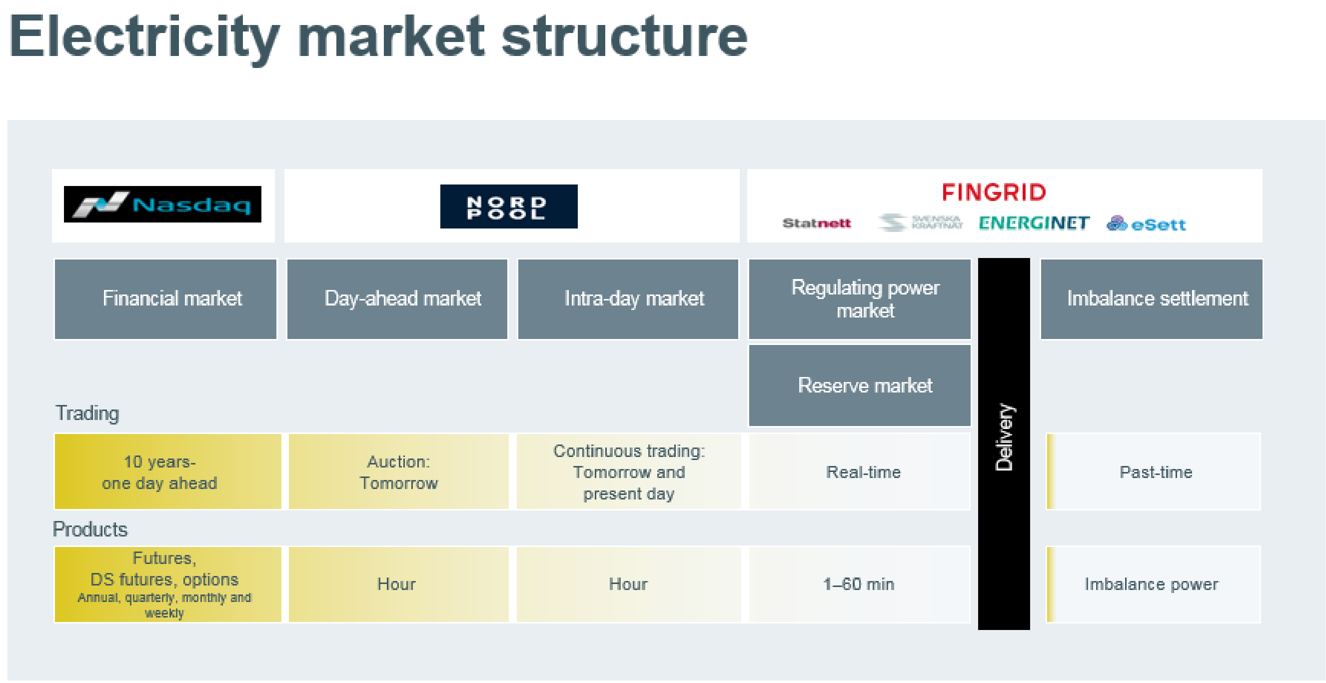

FIGURE 22 - ELECTRICITY MARKET STRUCTURE IN FINLAND (SOURCE: FINGRID)

Fingrid is responsible of the 400 kV, 220 kV and parts of the 110 kV voltage grid. There are cross-border grid connections from Finland to all neighbouring countries and these connections are under Fingrid’s responsibility. Finland, Sweden, Norway and eastern Denmark constitute the Nordic electric AC power system having the same grid frequency. Fingrid’s role in the electricity system is illustrated in Figure 23. The annual electrical energy consumed in Finland was 85.5 TWh in 2017 and the maximum hourly demand has been around 15 GW in 2016 [15]. Typically, the maximum demand is reached during the winter months when cold weather conditions increase the demand for heating and illumination to its peak. The power generation today (2018) is composed of an energy mix: 25 % nuclear energy, 23 % import, 15 % hydropower, 7 % wind generation, 24 % CHP and 6 % others [13]. It becomes evident that the share of electricity generated by wind and solar in Finland is still minor.

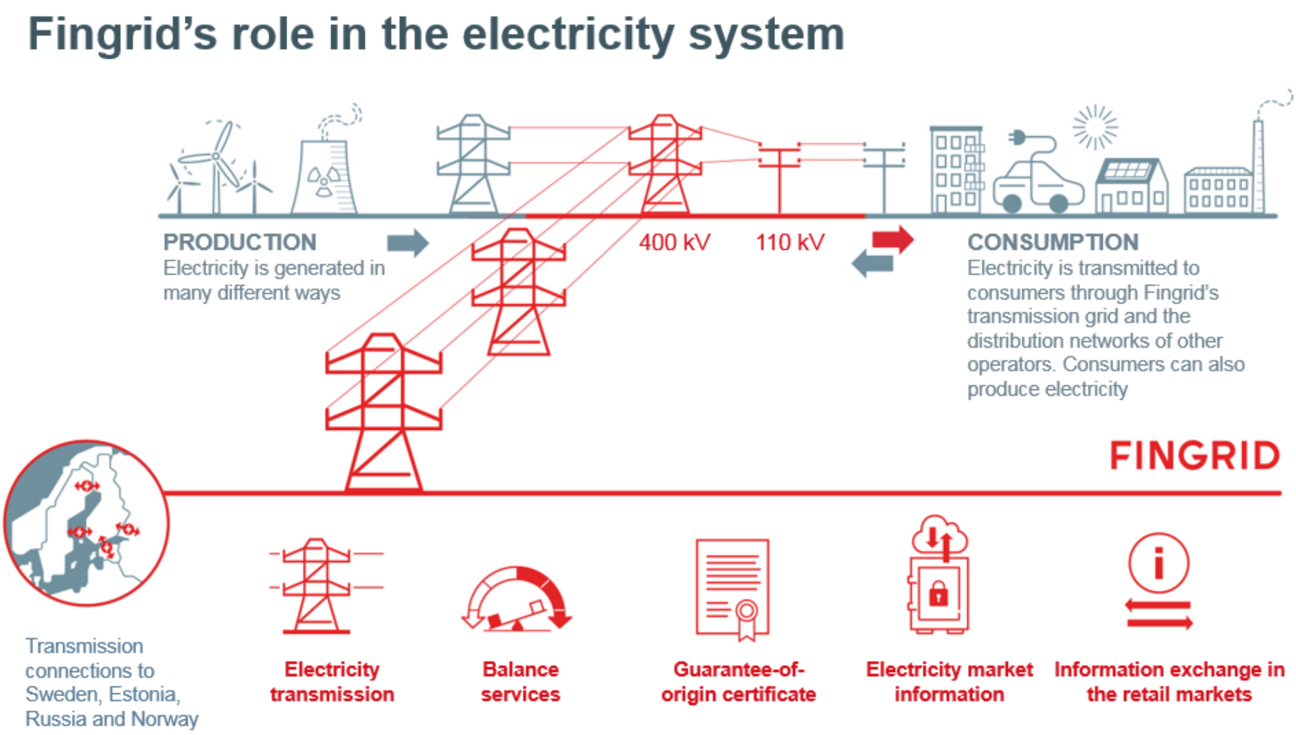

FIGURE 23 - FINGRID'S ROLE IN THE ELECTRICITY SYSTEM IN FINLAND (SOURCE: FINGRID [15]).

Helen Electricity Network Ltd.

In Finland, ca. 80 local DSOs take care of the electricity distribution. The distribution networks consist of medium voltage (MV: 20 kV and 10 kV) and low voltage (LV: 0.4 kV) networks. Some DSOs also have 110 kV networks. DSOs' operating area vary from urban networks with underground cabling to countryside areas with mainly overhead lines. Especially in city areas, MV networks are built in a ring structure but operated in an open loop structure. LV networks are build and operated in a radial structure.

In this Finnish demonstrator, Helen Electricity Network Ltd. (Helen Sähköverkko Oy, HSV) is the local licenced DSO in Helsinki. The geographical area is Helsinki (ca 187 km^2), the capital of Finland. HSV has 6400 km overhead lines and underground cables in total. One third of the 110 kV lines and practically all the medium and low voltage lines are underground cables. . Helen Electricity Network Ltd. has 383 000 customers. As graded in the number of customers, Helen Electricity Network Ltd. is the third biggest DSO in Finland.

HSV has three 400/110 kV connection points to the transmission network, 25 110/20(10) kV primary substations and 1845 secondary 20(10)/0.4 kV substations. Approximately 28 % of the secondary substations have distribution automation. The principled structure of the electricity distribution network in Helsinki is presented in Figure 24.

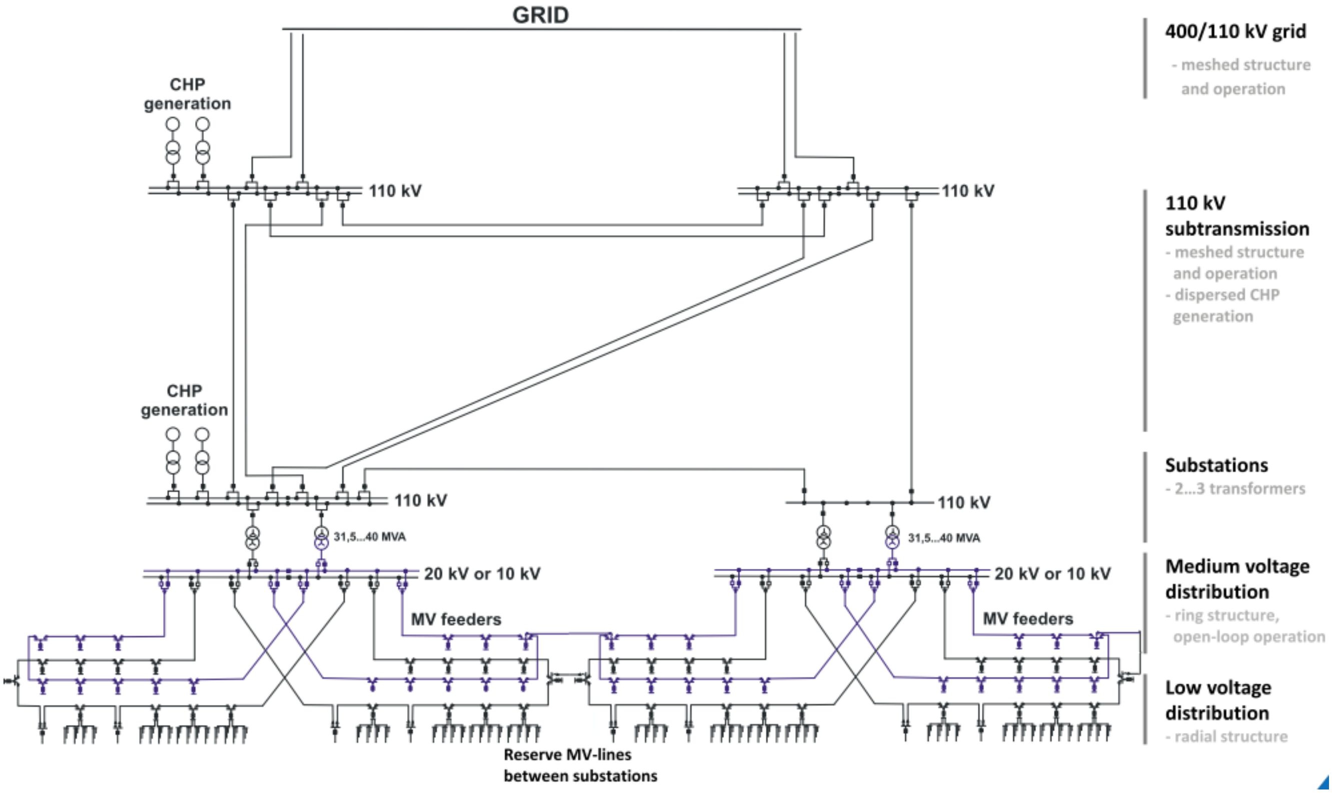

FIGURE 24 - THE PRINCIPLED STRUCTURE OF THE ELECTRICITY DISTRIBUTION NETWORK IN HELSINKI.

Assets in the Finnish demonstration

The assets used are a photovoltaic plant (850 kW_p), aggregated small battery storages (currently eight storages, potential 24 kW), one large-scale battery unit (1.2 MW, 600 kWh), residential heating loads (potential through AMR 20 MW) and public charging stations for electric vehicles (currently approximately 50 EV public charging stations). All assets are existing but their present readiness to perform in ancillary services varies. Currently, there is lack of communication infrastructure and partly the TSO's rules of ancillary services are under development for these smallest aggregated assets. One task for this demonstration is to define the data management requirements in the whole value chain in order to be able to scale the system from the demonstration to eventual future needs.

Photovoltaic generation capacity

Photovoltaic power plants in Suvilahti and Kivikko have a combined peak power output of 1 MW_p. The plants are connected to the medium voltage network and operated by Helen. The electricity production of the plants will not be limited in this demonstration, as the target is to ensure the maximum RES capacity. Trading of reactive power for the DSO from one of the PV plants is demonstrated within EU-SysFlex.

Aggregated small scale battery storages

In this demonstration, there are eight consumer-sized batteries with the overall capacity of 24 kW. Every additional battery sold to Helen's customers during and after the EU-Sysflex project will be automatically added to the flexibility pool and can be used to provide ancillary services. The development of an interface for the energy management system is on-going.

BESS

An industrial-scale battery energy storage system (BESS, connected to the 10 kV medium voltage network) is currently used as a research platform to study the operation and feasibility of large-scale batteries in power systems. An interface for the energy management system has already been implemented. In this demonstration, reserve markets and trading of reactive power capacity are natural target markets for a battery. The research study is active until August 2019 and after that the BESS will participate in FCR-N hourly reserve market following the market rules. The rated power output is 1.2 MW and the energy capacity 0,6 MWh, which can be fully utilised for demonstration purposes. However, due to market requirements, the BESS can participate in the market only with a restricted 600 kW power capacity. Fingrid is planning a new, fast market place where the whole capacity of BESS would be eligible but it is uncertain whether the market place will be opened during the EU-SysFlex project.

Residential heating loads with AMR

In Helsinki, the extensive roll out of AMR metering was finished by the end of 2013. Every customer has an AMR meter and access to his own consumption data via an internet platform. The DSO has the technical ability to control the electric storage heating of some residential customers via AMR meters. In the past, this load had been controlled based on the electricity market spot prices and heating demands that had been determined from temperature. The aggregated electric power of the controllable loads is approximately 20 MW. Now, within the vast change in the energy sector and the development of electricity markets, the residential electricity heating loads are an interesting flexible resource to be considered for the balancing power market.

In the demonstration, the technical integration of this type of load to the balancing power market by an aggregator is evaluated. However, the research done in the EU-SysFlex project has revealed issues in the current AMR meter reading system. The communication channel does not fulfil the requirement of balancing power market (mFRR, 15 minutes) for a large amount of AMR meters. The slowness in the meter reading system prevents the operation in balancing power markets. However, despite of the technical control challenge, the flexibility potential of AMR heating loads will be evaluated in the EU-SysFlex Finnish demonstration. New AMR meters and metering systems are coming in ca 10 years and the specifications are currently under discussions in Finland.

Public charging stations for electric vehicles

Public charging stations for electric vehicles are connected to the low voltage network and provide ca. 3 MW demand response capacity potential in total. Charging stations will utilise the same interface as the consumer batteries for interaction with the energy management system. Due to their capability for fast response time, charging stations are eligible for the reserve market.

The flexibility resources and at which voltage level they are connected are illustrated in Figure 25.

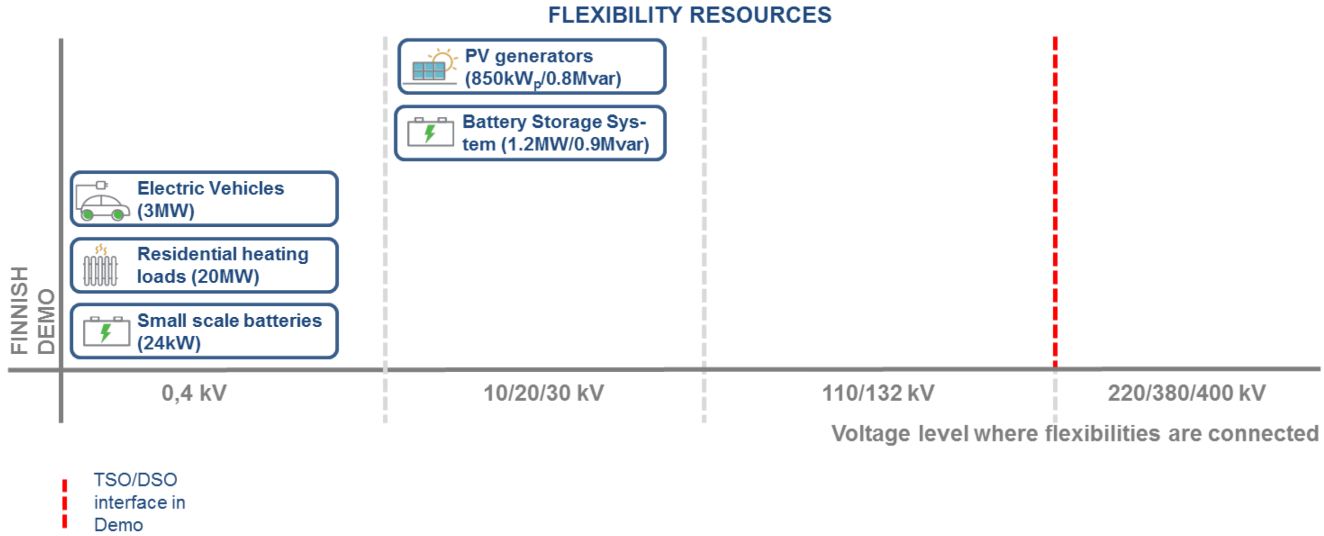

FIGURE 25 - CONNECTION POINT OF FLEXIBILITY RESOURCES IN THE FINNISH DEMONSTRATOR

4.7 TOOLS

The core tools to be developed during the project are a set of forecasting tools, a reactive power market mechanism (proof of concept) and a reactive power dispatch tool. In addition, the communication channels between the assets and the aggregation platform will be developed.

Forecasting tools and aggregation

The forecasting tools that are being developed during the project will make estimations of the available flexibility of the various assets based on data such a weather information as well as other data from internal and external sources. The output will be the available flexibilities for each type of assets and the market places where they could be traded. An aggregation platform will further decide how to form the appropriate bids. The detailed scope of the required features and functionalities will be made more precise during the course of the project.

Aggregation platform

An aggregation platform already exists in the aggregator's (Helen) system, but the communication channels with the small distributed assets are insufficient and need to be developed. To be able to aggregate small distributed assets to the TSO ancillary markets, the communication readiness must be developed between the assets and the aggregation platform. For example, currently, the communication channels of the large-scale BESS and aggregation platform and Helen's trading systems are under development and the goal is to trade the flexibility of the BESS to the TSO's ancillary markets.

Reactive power market mechanism and reactive power dispatch tool

For the trade of reactive power the market mechanism will be defined. An automatic tool for 110 kV compensation devices is already today in operation. A tool for answering the question whether additional reactive power resources will be asked from the DSO's market place will be developed (reactive power dispatch tool). While, in the beginning, the reactive power market will be activated only once a month, this new tool will be a stand-alone program for a DSO. The proof of concept of the reactive power market mechanism is formulated in the EU-SysFlex project.

4.8 APPLICABILITY AND LIMITATIONS

The results of this demonstration are applicable for the Finnish electricity market framework. The results will be fully scalable in the Finnish framework but scaling up from the demonstration-sized operation will eventually require the development of production scale software that is not in the scope of this demonstration. The applicability of the results in other European electricity market frameworks will be evaluated at the end of the project.

The capacity of the residential heating loads in this project is significant enough to demonstrate the process and behaviour of the assets in a reliable manner. Especially the demonstration that contain the public EV charging stations shall be first and foremost regarded as a proof of concept. The number of EVs in the Helsinki area is rather limited today which leads to a sporadic utilisation of the charging stations. The forecast accuracy is affected by the small amount of EV charges per day. Despite the current limitations, the demonstration will support further developments of the EV infrastructure.

In addition, there is a challenge regarding high amount of residential electric heating loads controlled by the present AMR meters and including them to the intraday markets of TSO. Requirements of the communication are hard to achieve for a large amount of AMRs with the present AMR technology and communication.

The TSOs market rules support the retailer's role as an aggregator. According to the current rules there are minimum bid sizes for each market and markets are only open for aggregators with own balance settlement. Currently resources are allowed to be aggregated only from one balance responsible. TSO Fingrid is piloting a project in which aggregation from multiple balances is enabled. Fingrid also lists the promotion of market-based consumption flexibility as one of their R&D focuses for 2016-2026 [19].

During the EU-SysFlex project one limitation that has to be faced in the reactive power control performed by the DSOs is the regulation. For a DSO, it is nowadays more beneficial to have own compensation devices and operate them for the reactive power than to buy the same reactive power as a service or a market product.

4.9 EXPECTED RESULTS

As a result of the project, the technical performance of a process for providing aggregated distributed resources to the TSOs reserve and DSO's reactive power market is demonstrated. The demonstration will also deliver a design and a proof of concept for a reactive power market where a retailer can offer flexibilities for reactive power to DSOs. Thus, DSOs could improve their reactive power management by using novel approaches.

In order to offer flexibilities connected to the LV or MV network to various markets, an estimate of the available capacity/dispatchable power is needed. For this, a forecasting tool is being developed during the project. Connecting different types of flexibilities to the power system is one of the key factors in enabling the increased integration of renewable energy sources to the grid.

Figure 26 shows at which voltage level the assets providing flexibilities are connected and where they are offered to. It illustrates that in the Finnish Demonstrator the active power flexibility is offered from the low and medium voltage levels to the transmission level and that the reactive power flexibilities (BESS, PV power plant in MV level) are offered for the DSO needs at the interconnection with the TSO.

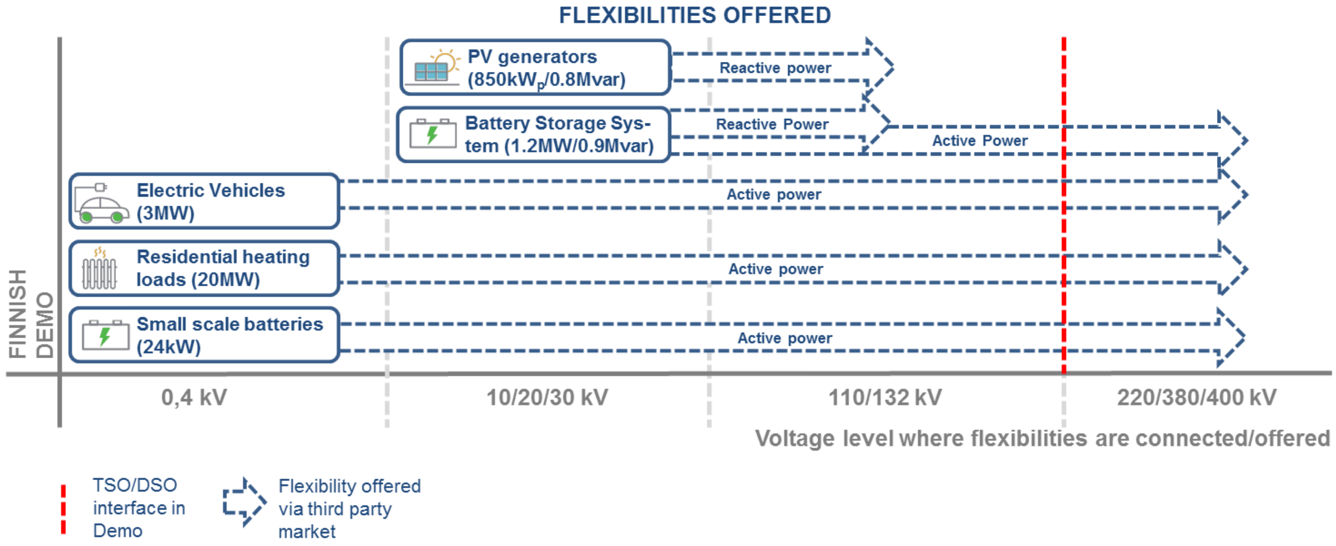

FIGURE 26 - FLEXIBILITIES OFFERED IN THE FINNISH DEMONSTRATOR

Figure 27 furthermore displays which scarcities these flexibilities solve. In the Finnish demonstrator, the flexibilities are used to provide frequency stabilization services to the TSO and help the DSO manage its reactive power exchanges with the TSO. The reactive power control of the DSO aims to stay within the PQ-window limits set by the TSO and eventually, if the DSO stays within the limits, it helps the reactive power and voltage control of the TSO. They are both developed with a market-based approach.

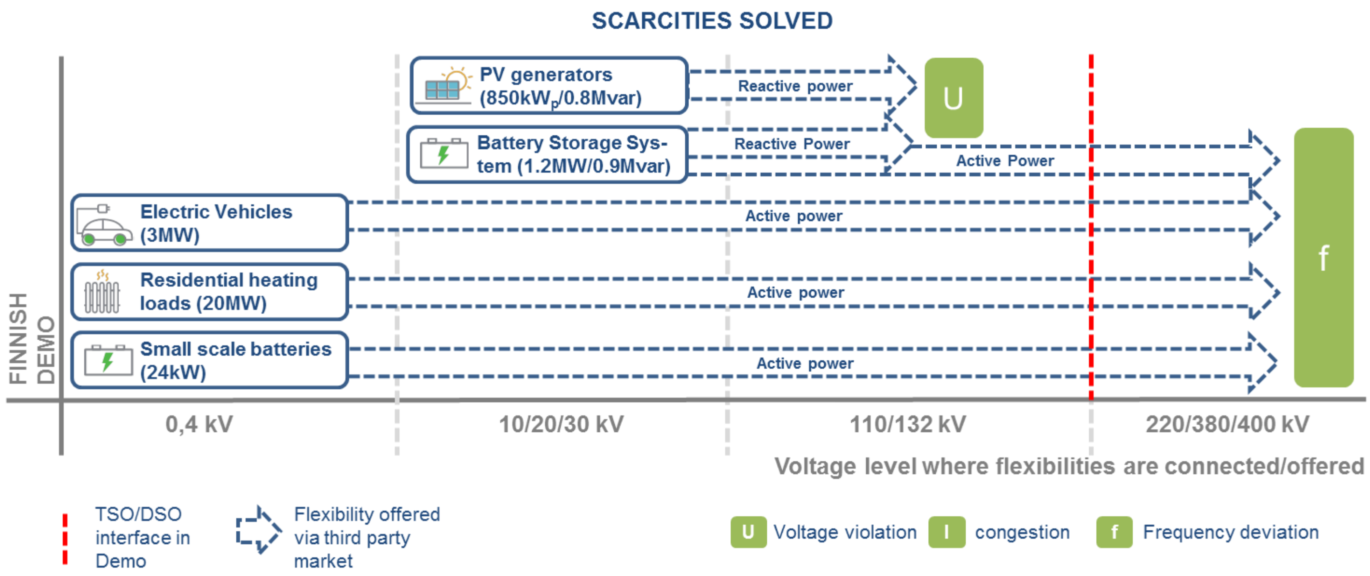

FIGURE 27 - SCARCITIES SOLVED BY FLEXIBILITIES IN THE FINNISH DEMONSTRATOR

5. COMMON VIEW

By means of the three demonstrators, already detailed in the previous chapters, which are located in Germany, Italy and Finland, EU-SysFlex [WP6] is analysing and testing the opportunities arising from decentralised flexibilities resources to serve the overall system needs. Figure 28 shows the location of the three WP6 demonstrations and gives a short overview of their main focus.

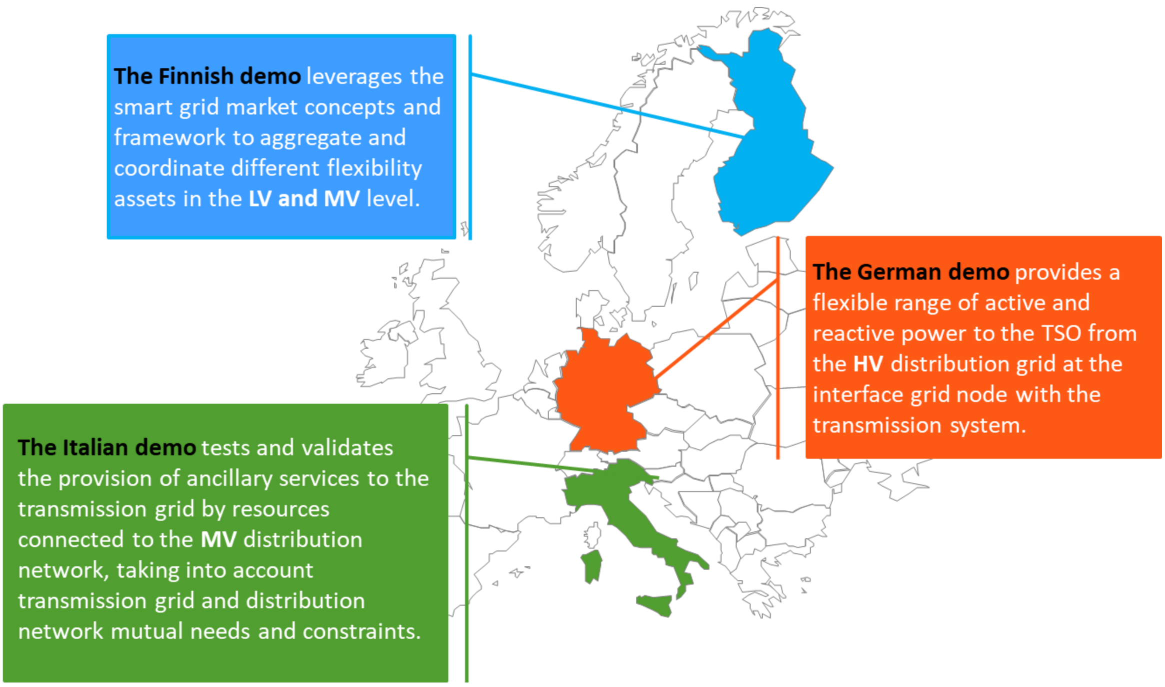

FIGURE 28 -DEMONSTRATORS OF WP6 EU-SYSFLEX

The three previous chapters (chapters 2, 3 and 4) describe the three different demonstrators individually depicting their specific background, innovation and set-up. From the previous chapters it becomes clear that the different demonstration set-ups have many similarities as well as differences. In order to understand better how they complement each other the following sections analyse the complementarity of the demonstrations and illustrate the common view of WP6 on the three demonstrators. Furthermore, this chapter focuses on how the three demonstrators complementarily help analysing and testing ways to take advantage of the opportunities arising from decentralised flexibilities resources to serve the TSO and DSO needs.

5.1 COMMON VIEW ON THE DEMONSTRATORS' FLEXIBILITIES SOURCES AND SCARCITIES SOLVED

The three demonstrators use different flexibility resources that are all connected to different voltage levels. Figure 29 illustrates the types of flexibility resources used in each demonstrator. It furthermore depicts how much capacity is potentially available in the demonstrator for each flexibility source. In addition, it shows at which voltage level this type of flexibility source is connected to. For example, in the Finnish demonstrator the inverter of a photovoltaic (PV) generator is used as reactive power compensation resource, which contributes with 0.8 Mvar to the flexibility potential made available through the demonstrator. This PV generator is connected to the medium voltage (20 kV) level. As an addition example, the Italian demonstrator uses two STATCOMS as flexibility resources, which make two times 1.2 Mvar available as potential flexibility.

Additionally, in the figure, a red dot line between two voltage levels illustrates the location of the TSO/DSO interface as it varies from country to country and therefore also in the demonstrators. For example, in Germany the border between DSO and TSO is located between the HV (110 kV) and EHV (220 kV and 380 kV) level.

Figure 29 shows that several types of flexibility resources are tested within the field tests of the WP6 demonstrators. It provides a broad picture of how the many different technologies used at different voltage levels, with different locations for the TSO/DSO interface can complement each other. This includes end consumer assets as well as DSO owned assets, small and bigger scale generation units as wells as renewable and conventional plants.

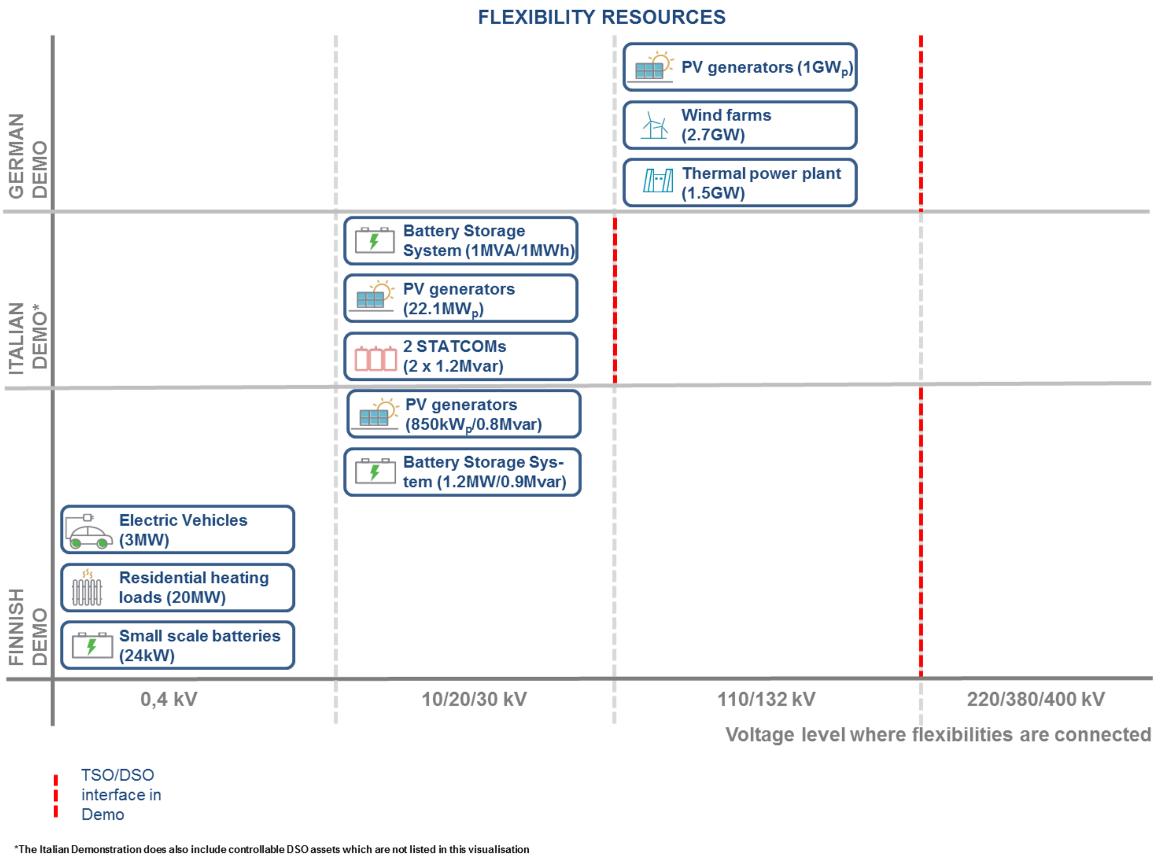

FIGURE 29 - FLEXIBILITY RESOURCES IN THE DIFFERENT DEMONSTRATORS

In addition to the message given by Figure 29, Figure 30 adds more information to the same base illustration. It shows what kind of flexibilities, namely active or reactive power, each resource offers and to which voltage level they are offered. The different types of arrows indicate how the flexibilities are offered – either via a third party market or without any third party market in between.

It can be seen that some flexibilities are offered from the distribution grid to the distribution grid, but others also from the distribution grid to the transmission grid level across the TSO/DSO interface. Additionally, in some cases, the flexibilities are also used within the same voltage level they are connected to. Furthermore, it shows that some resources deliver only active or reactive power, whereas others can deliver both.

For example in the Finnish Demonstration, the inverters of a PV power plant offer reactive power only to the benefit of 110 kV voltage level, whereas the BESS offers both active power to the 400 kV (TSO level) and reactive power to the benefit of 110 kV level. In the German demonstration all three types of flexibility resources, namely wind farms, PV generators and conventional plants, offer active as well as reactive power to the EHV grid, but at the same time, the DSO also uses these flexibilities for congestion management and voltage control within its own 110 kV grid. As explained above, Figure 30 also illustrates if flexibilities are offered via a third party or not. For example, the Finnish Demonstrator offers reactive power to the DSO as well as active power to the TSO market via a third party, whereas the Italian as well as the German Demonstrators offer the flexibilities without a third party market. In the Finnish demonstration, the TSO is the market operator in the ancillary markets (active power) and DSO is the market operator of reactive power market (proof of concept).

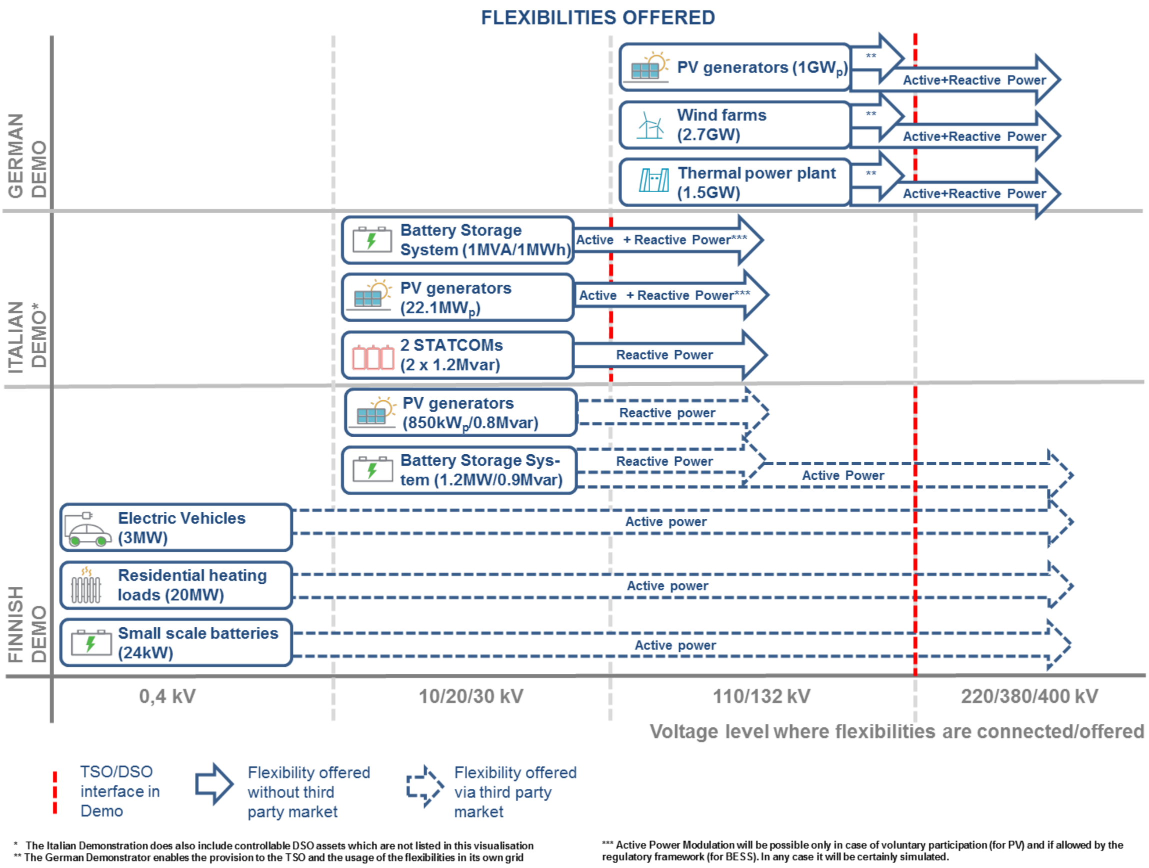

FIGURE 30 - FLEXIBILITIES OFFERED BY THE THREE DEMONSTRATORS

Figure 31 adds the information of which scarcities are solved with the help of the flexible resources used in the demonstrators. These scarcities are voltage violation, congestion and frequency deviations.

In each demonstrator, 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.

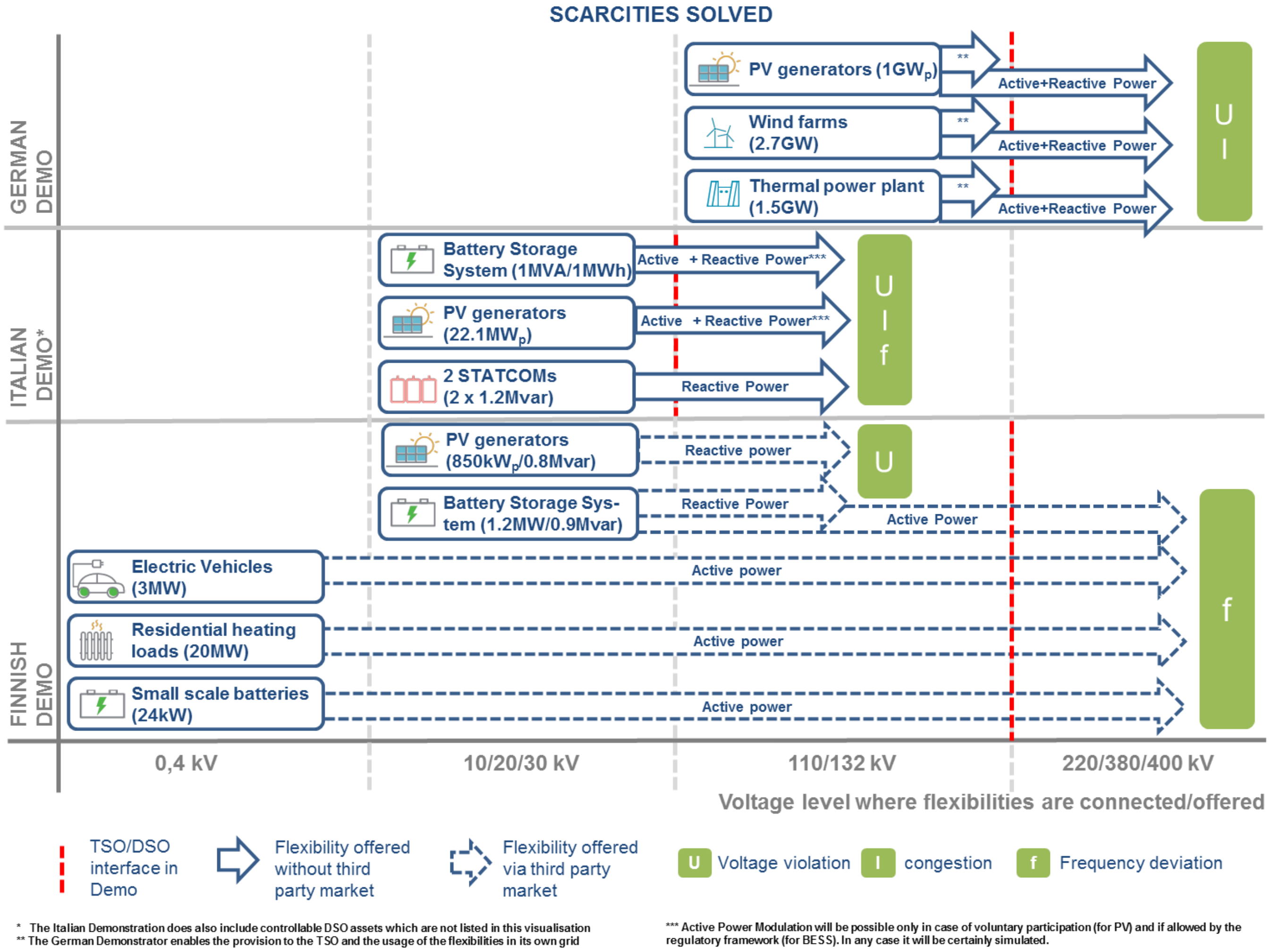

FIGURE 31 - SCARCITIES SOLVED BY THE FLEXIBILITIES IN THE THREE DEMONSTRATIONS

The three illustrations (Figure 29, Figure 30 and Figure 31) show how the WP6 demonstrators can complement each other by using varied resources connected to different voltage levels in order to provide different services and solve a set of scarcities.

5.2 COMMON VIEW ON THE DEMONSTRATORS' PROCESS OF FLEXIBILITY SELECTION

Whereas the description of the complementarity in the previous section focused on the flexibility resources and the scarcities addressed in the demonstrators, this section, with Figure 32 and Figure 33, depict the process of selecting flexibilities for active and reactive power, taking into account the interactions between DSOs, TSOs and distributed energy resources (DER) - or, if applicable, the DER aggregator on their behalf. Therefore, the boxes in the following figures describe the action of a specific stakeholder and its interaction with other stakeholders. Differences and similarities apply depending on the addressed scarcity, the user of flexibilities and therefore also the location of the clearing process.

Figure 32 illustrates this flexibility selection process for active power within the three demonstrators. In the German Demonstrator, the DER sends the 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 and sends the signal to the DER aggregator, which adapts the active power of its asset. Active power in the German Demonstrator is used for congestion management and in very few cases for voltage control.

In the Italian Demonstrator, active power is used 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.

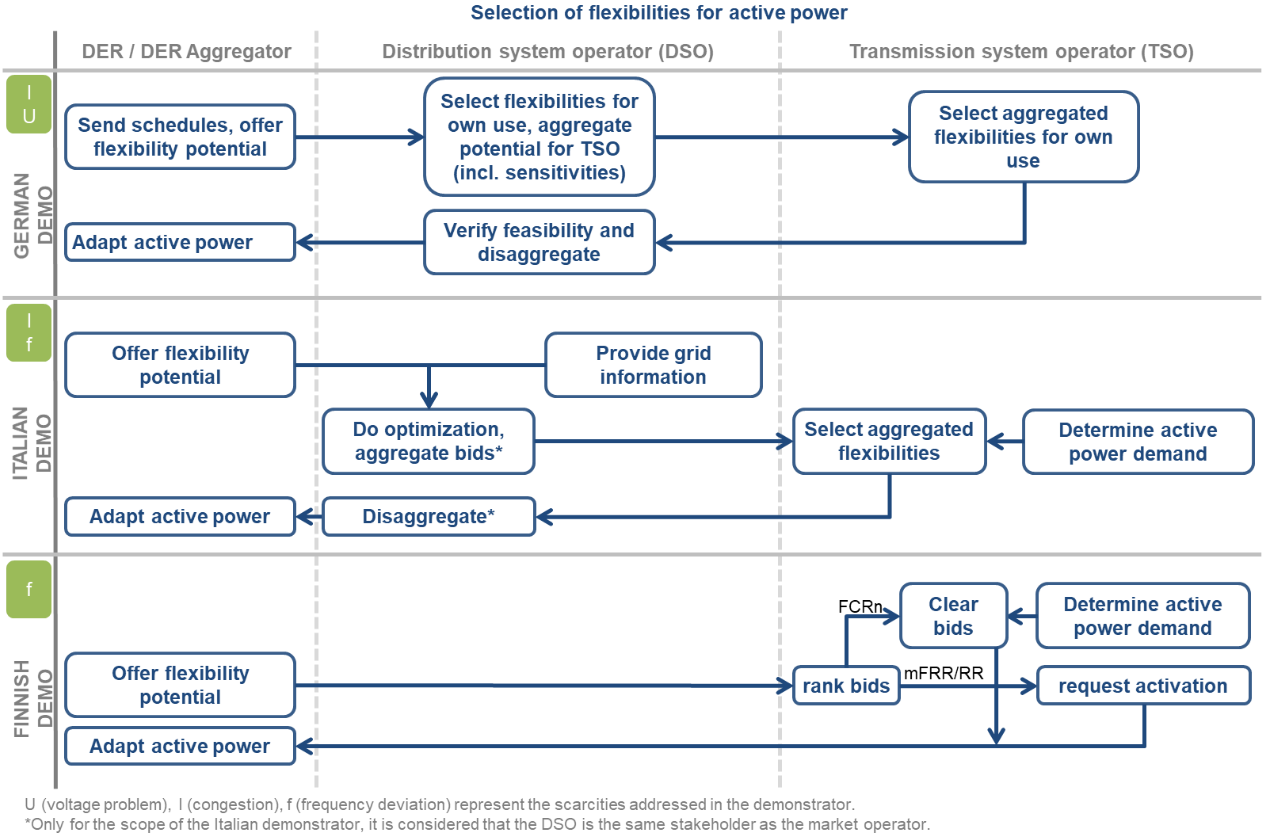

FIGURE 32 - SELECTION OF FLEXIBILITIES FOR ACTIVE POWER IN THE THREE DEMONSTRATIONS

Figure 33 shows the analogue of flexibility selection process for reactive power within the three demonstrators. In the Italian Demonstrator, at first, the DER determines the reactive power potential and sends it to the DSO. The DSO aggregates the reactive power potential for the TSO, and then the TSO determines its reactive power demand. The DSO verifies and disaggregates the request so that the DER can adapt the operation.

In the German Demonstrator, the DER sends active power schedules to the DSO, which determines the units' reactive power potential based on their grid connection contract. The DSO selects the flexibilities for its own use and aggregates the potential at the grid connection point to the TSO for reactive power. The TSO determines its reactive power demand and sends this information to the DSO. The DSO checks the feasibility and disaggregates in order to send reactive power set points to the DER.

Since the Finnish demonstrator is situated in the low and medium voltage, reactive power is solely provided to the benefit of the DSO due to its very local nature. The process depicts the flexibility selection on a monthly basis. The DER offers their potential to the DSO, which undertakes a market clearing based on its reactive power demand. The result of the market clearing is forwarded to the DER in order to know the new delivery obligations. Currently, no DSO reactive power market exists and a proof of concept with two DERs (battery energy storage system and PV power plant) will be demonstrated during EU-SysFlex.

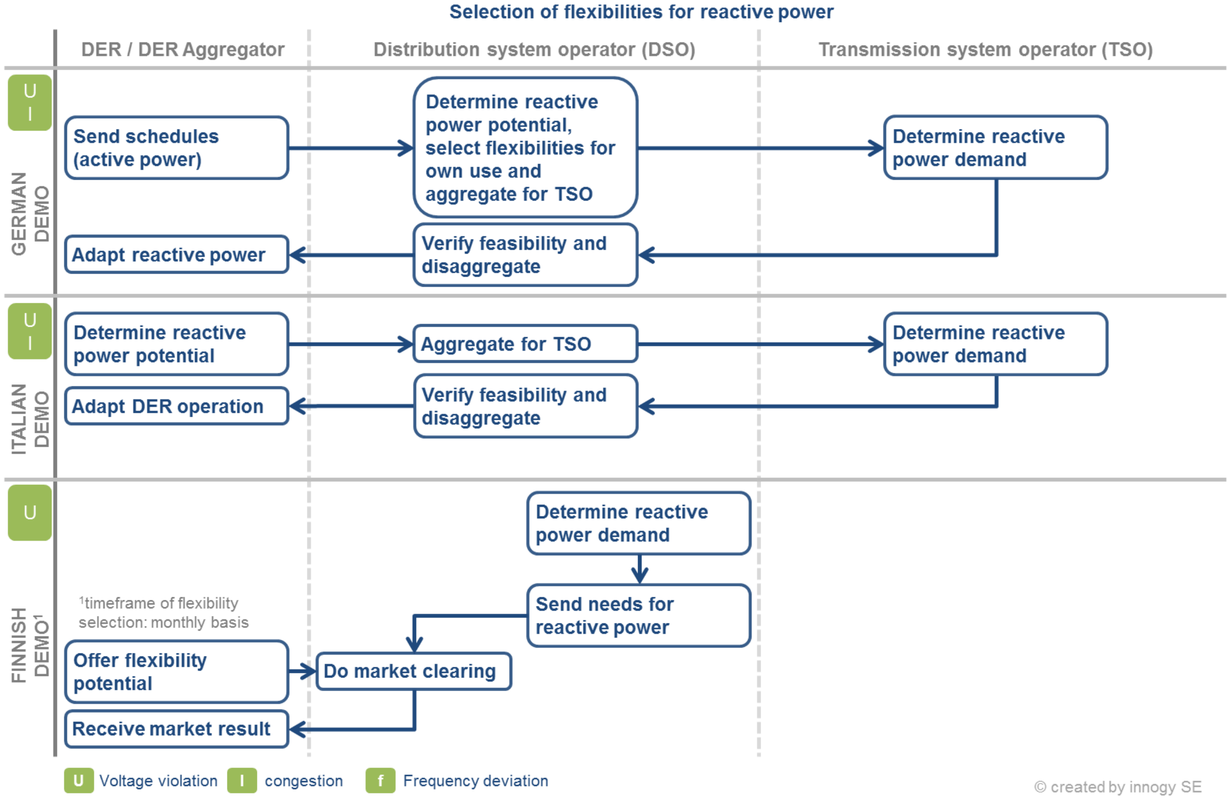

FIGURE 33 - SELECTION OF FLEXIBILITIES FOR REACTIVE POWER IN THE THREE DEMONSTRATORS

Between all Demonstrators, similarities and differences can be detected. For active power, differences are mainly between the Finnish demonstrator on the one side and the German and Italian demonstrators on the other side. Since the Finnish demonstrator focuses on frequency reserve delivered by DER connected to a congestion-free distribution grid, the clearing process (matching offers and demand) for each individual DER is carried out by the TSO and the aggregator with no involvement of the DSO. As a contrast, the German and Italian demonstrators involve grids that show congestion problems and therefore the clearing process requires a validation by the DSO. Consequently, the aggregated list of flexibilities received by the TSO is limited by the potential congestions that their activation would cause. Additionally, the German demonstrator uses flexibilities to solve congestions in its own grid that occur even without the flexibility activation by the TSO.

For reactive power, differences apply in the involvement of the TSO and the selection process of flexibilities. Since the Finnish demonstrator encompasses low/medium voltage assets, reactive power management is carried out only for addressing scarcities in the distribution grid, whereas the Italian demonstrator uses reactive power to solve TSO scarcities and the German demonstrator for solving both TSO and DSO scarcities. Therefore, in analogy to active power management, the TSO receives in both demonstrators an aggregated list of flexibilities for reactive power management in order to reflect the DSO needs of a grid within its technical limits for voltage and current. Another difference is the timeframe, since the Finnish demonstrator already pre-selects reactive power flexibilities on a monthly basis, whereas the German sends a forecast of a potential reactive power window day-ahead, but selects resources just the same as the Italian demonstrator intra-day or real-time.

5.3 COMMON VIEW ON DEMONSTRATORS' TSO/DSO COORDINATION

All three demonstrators validate the concept of TSO/DSO coordination even though the technical set-ups differ. This is clearly evident for the Italian and German demonstrator, as their approach for TSO/DSO coordination is similar. As detailed in section 0, in both demonstrators the TSO sends a request directly to the DSO informing about what kind of flexibilities are needed. It is then the DSO's responsibility to actually fulfil this request (for congestion). The TSO is therefore not directly controlling any assets, devices and generation units connected to the distribution networks, since this may create problems such as congestion in the distribution grid. The DSOs take care that the TSO requests are fulfilled but in such a way that no additional congestion is created in the distribution grid guaranteeing a congestion free, secure and reliable distribution system operation.

The Finnish demonstrator is a little different. This Demonstrator adds the retail view to WP6. It shows how to fulfil the needs of TSO (active power) and DSOs (reactive power) from a retail perspective. This adds the aspect of dealing with potentially occurring competition between DSO and TSO having the interest in making use of the same flexibilities. This is an important additional aspect for WP6 as it is a different view on sharing responsibility and of being liable for the services that need to be provided to the one or the other system operator. The Finnish demonstrator therefore has no specific task about TSO/DSO coordination and TSO/DSO data exchange. This needed data transfer topics are therefore considered more dominantly in the Italian and German demonstrators.

5.4 COMPLEMENTARITY OF THE DEMOS

The three demonstrators are set up as field tests in different countries and in different grids showing the feasibility of different flexibility provision from the distribution grid to higher voltage levels including to the transmission grid.

More than that, it shows in theory that the three different demonstrators could work hand in hand, also in the same grid infrastructure and complementarily work together. Figure 34 shows how a theoretical set up of the three demonstrators all together could take place. It illustrates the flexibilities resources in the demonstrators and where they are connected, not individually but in one and the same theoretical grid infrastructure.

In addition to the flexibility resources already presented in chapter 5.1, Figure 34 also includes further DSO asset integrated in the demonstrations such as an on-load tap changer (OLTC) at the HV/MV transformer of the Italian demonstrator.

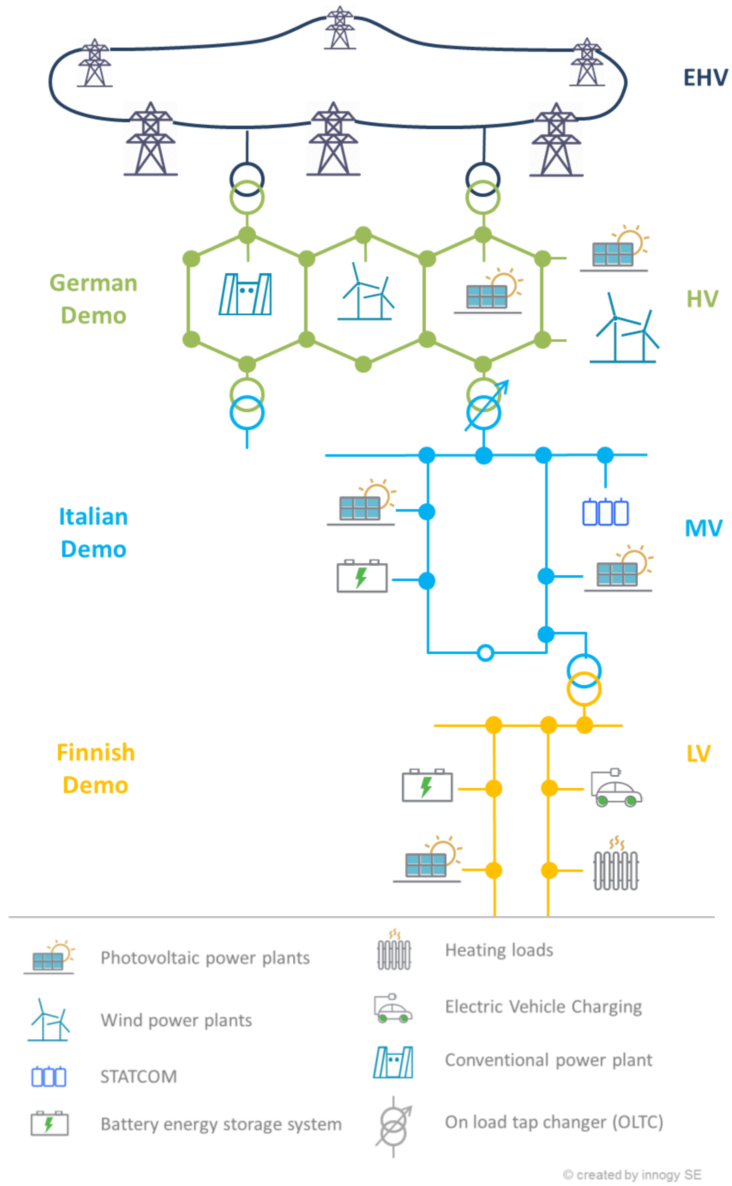

FIGURE 34 - COMPLEMENTARITY OF THE 3 DEMONSTRATORS IN ONE THEORETICAL GRID INFRASTRUCTURE

Figure 35 shows the theoretical interlink in this simplified grid infrastructure and how the demonstrations could complement each other. It illustrates how the flexibility offers, the demand and the actual delivery are exchanged between the voltage levels. On a certain voltage level, flexibilities from the same or from the underlying voltage level can be applied. When considering from the flexibilities side, flexibilities can be offered for the benefit of the voltage level they are connected to or of any higher level.

Furthermore, all flexibilities can offer their contribution to solving the scarcity of frequency reserves. In the Italian demonstrators, after a prequalification and notification to the respective DSO, the flexibility service provider can directly offer their flexibilities to the TSO. In the Finnish demonstration, the DSO does not take part in the frequency control. In the German Demonstration, no flexibilities are directly used for frequency stability, but network capacities are reserved for assets having been marketed in the frequency flexibility market.

The three demonstrators show that, with this interlink, they could work hand in hand to provide flexibility independently of where the TSO/DSO interface is located in the grid and of how the limitations at the interface are managed between the different actors.

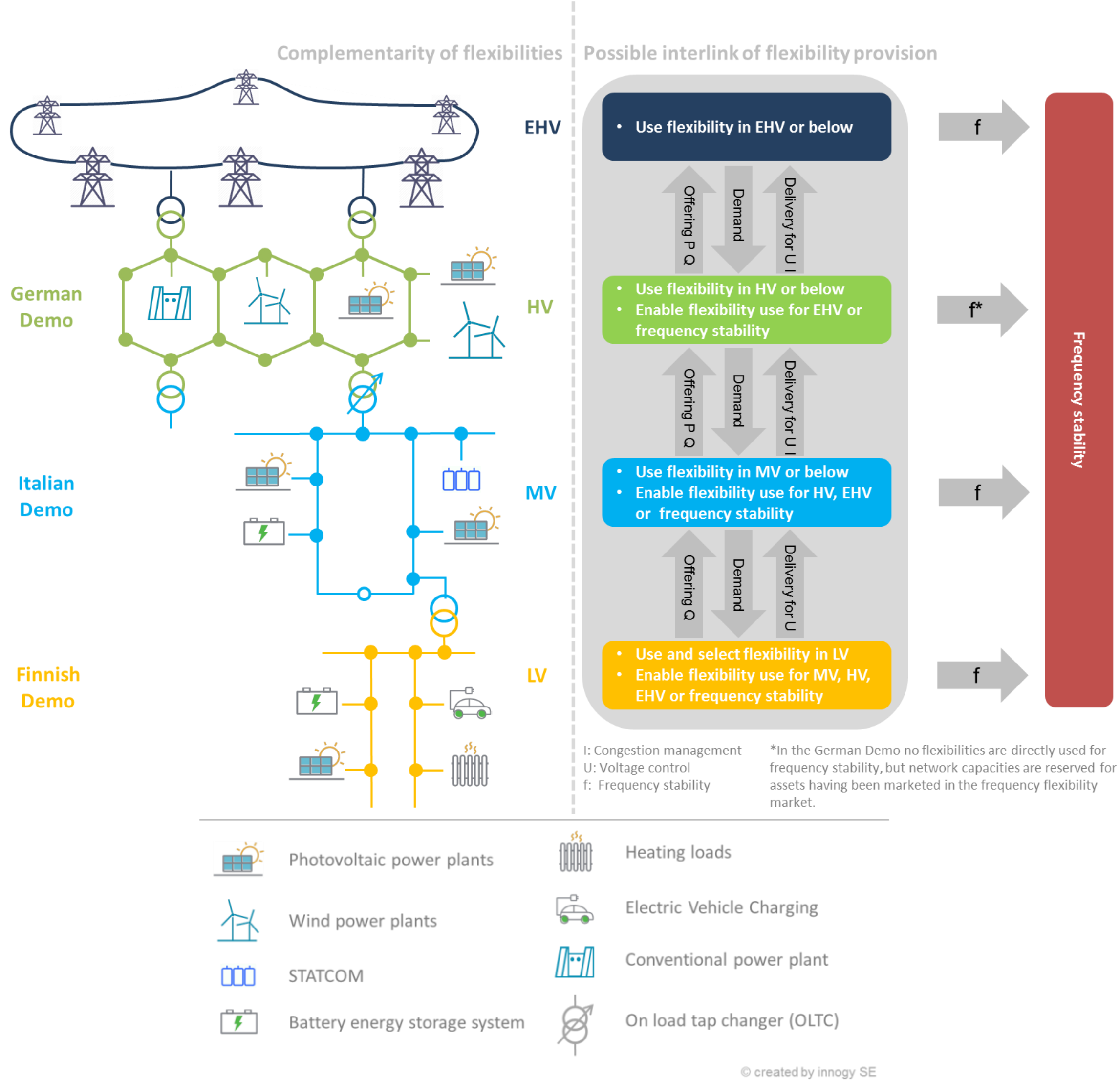

FIGURE 35 - POSSIBLE THEORETICAL INTERLINK BETWEEN DEMONSTRATIONS FOR FLEXIBILITY PROVISION

5.5 CONCLUDING COMMON VIEW

All demonstrations have similarities when using both active and reactive power as flexibilities from the distribution grid. Differences arise from the assets used, the voltage levels they are connected to, the technical set-ups and the regulatory frameworks they are submitted to. Still they all work to solve similar technical scarcities in the system. In addition to these technical aspects, they all contribute to finding cost efficient solutions to utilize flexibilities connected to the distribution grid in the most economical way.

It can be concluded that the three demonstrators complement each other for reaching the WP6 objectives of

- Improving TSO-DSO coordination;
- Providing ancillary services to TSOs from distribution system connected flexibilities;
- Investigating how these flexibilities could meet the needs of both TSOs and DSOs.

All three demonstrations enable the provision of flexibilities as ancillary services to TSOs from resources connected to the distribution system considering both active and reactive power. However, some limitations apply to physical set-ups due to regulatory constraints: currently, in the German demonstrator case, it is possible to exploit active power flexibilities from private generators only on a voluntary basis (presently there are no regulations for flexibility market at distribution level).

Furthermore, the three Demonstrators include different characteristics of interfaces between the distribution and the transmission networks. Indeed, for the Italian and Finnish demonstrators, the boundary corresponds to the single connection (in Italy a single primary substation, in Finland a single PQ-window with 3 connection points to the TSO), while in the German Demonstrator 16 interconnection points (16 EHV/HV substations) with the transmission network are included. This allows the German Demonstrator to use re-dispatching as a control lever for congestion management. On the other hand, it is not possible in the German and Finnish Demonstrator to use on-load tap changers (OLTCs) of TSO/DSO connection point since they are managed and owned by the TSO. In contrast, the Italian Demonstrators does use OLTCs for voltage control measures. These peculiarities potentially allow a complete replicability of the tested smart grid solutions for different network frameworks improving the TSO-DSO coordination. Concluding, by means of the planned field tests all three demonstrations support investigating how these flexibilities could meet the needs of both TSOs and DSOs.

The analysis of this chapter highlights the benefit of the demonstrations and the way they complement each other in respect to WP6 objectives and, from a broader perspective, to the EU-SysFlex project objectives. Furthermore, it becomes evident that the demonstrations do not only contribute together the common objective but could theoretically work hand in hand interlinked with each other. Flexibilities from all the voltage levels support together the joint goal of all the demonstrators, which is to support the efficient and coordinated use of flexibilities for the integration of a large share of renewable energy resources and for the benefit of a well operating power system.

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