edgeFLEX

D5.4

Report of the field trials of slow and fast dynamics in Germany

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Abstract
The goal of the edgeFLEX SWW trial, located in Wunsiedel Germany, is to test and evaluate the edgeFLEX services supporting new concepts of power grid management and energy chain supply by enabling the use of local flexibility which could be traded on a local energy market. These services aim to provide support for the energy supply system both under normal operating conditions (slow dynamics), and for network system stability (fast dynamics). The testing has demonstrated that available local flexibility can be leveraged to overcome grid events such as over voltage, in addition to supporting energy supply by utilising the VPP and energy community, through using existing EMS, newly developed advanced edgePMUs and the edgeFLEX Platform components, services and interfaces.

Keyword list
Slow dynamic, Fast dynamic, VPP, Energy Community, edgePMU, 5G, User Engagement, Voltage control, EMS

Disclaimer
All information provided reflects the status of the edgeFLEX project at the time of writing and may be subject to change.

Executive Summary

This document describes field trials of novel services for energy provision performed in a live operating power grid in Wunsiedel, Germany. The concepts deployed were developed in earlier stages of the project within work packages WP1, WP2, WP3 & WP4. The services performed are slow dynamics services, meaning that these services are used as power balancing services, and fast dynamics services, meaning that these services provide power supply supporting ancillary services used to maintain and restore system stability and operation. The infrastructure and layout of the tests are described in detail including the set-up and integration process, the services examined, and the business approach and the test scenarios explored.

The business focused approach demonstrates how the Distribution System Operator (DSO) might assume new roles and responsibilities while ensuring they have an extended level of control to respond to grid events.

In the preparation phase of the trial, suitable locations were identified, and stakeholders were approached to ascertain their level of engagement in the local energy chain of supply with the goal of establishing an Energy Community (EC).

In addition, measurement devices and data collection capabilities were examined together with 5G communication potential to achieve unobstructed data transfer between local measurements, the installed Energy Management System (EMS) and the edgeFLEX Platform developed in the scope of WP4.

Finally, the slow and fast dynamic services were defined, and the tests and their goals were parametrised.

The following issues were tested in the field trial:

- The operation of voltage control under over voltage conditions, and
- The operation of an Energy Community as a Virtual Power Plant (VPP).

Each test conducted demonstrates how engaging flexibility with the EC addresses changes on the grid because of the above scenarios. Specifically, the voltage control tests demonstrated how an over voltage event can be resolved using energy flexibility, in which the over voltage event acts as a request which needs to be fulfilled by flexibility. The EC as a VPP test used multiple assets providing flexibility and demonstrates the feasibility of involving multiple entities to resolve grid events.

Additionally, as part of the voltage control tests, flexibility offers and their potential as a service for congestion management was observed. A storyline for the support of redispatching issues was derived from the results of these observations.

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Introduction

With the dramatic growth in the use of renewable energy, VPPs need to support both the integration of intermittent Renewable Energy Sources (RES) and Distributed Energy Resources (DER) into their operations. This leads to challenges and the combination of DER and RES into a new generation of VPPs needs to be optimised to provide supportive grid flexibility. Day-to-day grid operations are planned in advanced, whereas energy is traded on the day ahead and intra-day markets. This type of service provisioning requires long reaction times to generate the amount of energy needed and is referred to as “slow dynamics”. Additionally, ancillary services to provide fast frequency, inertial response and dynamic-phasor driven voltage control to support grid operations are also necessary, as these types of services address real-time deviation issues. This is referred to as “fast dynamic”.

With these issues in mind, the edgeFLEX trial in Wunsiedel aims to promote the evolution of VPPs using the concepts developed in the project and to test the implementations of some of the research results of edgeFLEX in the live network of the DSO SWW. EdgeFLEX proposes that today’s VPPs, termed VPP1.0 by edgeFLEX, and which generate and store power with large RES assets with the VPP acting as the aggregator, should evolve to become VPP2.0s, in which a higher rate of RES penetration and the integration of smaller RES assets is achieved enabling increased citizen participation and the support of Energy Communities. The Wunsiedel field trial includes such citizen participation and the support of an Energy Community.

This document describes the planning, establishment, operation and results of the field trial for fast and slow dynamics conducted in Wunsiedel at SWW GmbH. The field trial consists of tests of the feasibility of operating flexibility-based innovative services, and service enablers, developed by edgeFLEX, in a real, live local distribution system. The “slow dynamic” and “fast dynamic” relate to services for electrical network operation under normal conditions. Slow dynamic services are used to supply energy to customers, and to maintain the balance between energy production and consumption. Fast-dynamic services aim to stabilize the power flows inside a power system using ancillary services such as that of Voltage Control.

An additional aim of the trial was the investigation of changes regarding decentralized energy production and trading expected to be introduced in future power grids. An Energy Community was created to investigate the potential and viability of including an Energy Community in the energy chain. Furthermore, the measurement hardware developed within the edgeFLEX project, the edgePMU, was deployed in the live grid infrastructure to capture data in the field and provide improved grid visibility of the network status and the edgePMUs were used together with the edgeFLEX Platform, the Policy Based Grid Management (PBGM) system and KIBERnet market platform to enable the generation and provisioning of flexibility offers for a local energy market, demonstrating the role which local grid control, enabled by ancillary services and an Energy Community, can play in enabling a VPP to expand its role in providing flexibility to the grid.

The SWW trial directly leveraged outputs developed by work packages WP1-4. In WP1, voltage control concepts for the VPP in both medium and low voltage grids were developed. In WP2, concepts for frequency response and inertia estimation were developed. In WP3, the edgePMU and communication requirements were established. WP4 defined the edgeFLEX Platform architecture which describes how the outputs from WP1-3 would integrate into the system, in addition to developing the Policy Based Network Management system (SLA Broker) and the KIBERnet market platform. SWW worked closely with WP6 to examine how the results from the trial could be implemented in the real-world in terms of regulatory requirements, target audience and development of appropriate business models. Finally, as part of WP7, SWW conducted trial site open days to promote the edgeFLEX solution in Wunsiedel. This event enabled the project to gather feedback from stakeholders and end-users on the implemented edgeFLEX solution.

1.1 Objective of this Report

The main objective of this document is to present the preparation, operation and results of the field trial carried out in the SWW power grid testing slow and fast dynamics services. This document describes the field trial preparation process from both the technical and societal perspectives as well as the integration of the edgeFLEX Platform, its components, the edgeFLEX market trading platform and edgeFLEX control services into the power grid infrastructure of SWW.

1.2 Outline of the Report

Chapter 2 describes the concepts of the slow and fast dynamic services deployed in the SWW trial. In chapter 3, the goals of the field trial are described. The preparation for integration and set up are illustrated including the method of site selection and hardware installation. In addition, the tests carried out are described and their significance to the trial and the edgeFLEX solution is presented. The final chapter presents the conclusions of the field trial.

1.3 How to read this Document

The document can be read as a stand-alone document. However, other deliverables of edgeFLEX offer more detailed information on specific topics relevant to this field trial which the reader may find useful as context information. The preparation of the exploitation of the results of the SWW field trial is a commercial setting is one of the topics described in D6.2.

The following edgeFLEX deliverables are relevant to the SWW field trial:

- D2.2 – Frequency control concept for current VPPs in large scale deployment: This report describes frequency control and metering strategies for VPPs at the transmission and/or distribution voltage levels.
- D2.3 – Frequency Control Concepts for Energy Communities with future VPPs: This deliverable describes the frequency control concepts and algorithms developed for future VPPs and energy communities.
- D3.1 – 5G ICT requirements, development and testing for edgeFLEX solution: This deliverable defines the 5G ICT requirements of the edgeFLEX services and enablers, as well as the timescale for 5G ICT solutions to be commercially deployed.
- D3.2 – Report on VPP optimisation, V1: The two versions of the deliverable reports on progress on the topics of VPP optimisation to balance variable, novel spatio-temporal wind forecasting method and optimising the RES operational costs in year 1 and year 2.
- D3.3 – Report on VPP optimisation, V2 (M12): The two versions of the deliverable reports on progress on the topics of VPP optimisation to balance variable, novel spatio-temporal wind forecasting method and optimising the RES operational costs in year 1 and year 2.
- D4.1 – Definition of overall edgeFLEX System Architecture: This report describes the details of the overall architecture used for the implementation and virtualization of the edgeFLEX services.
- D4.2 – Description of edgeFLEX MVP: This report describes the software components and services that form the MVP and look at how they combine to form the MVP in a way that has flexibility, modularity, the user and the VPP at its core.
- D4.3 – Description of internal interfaces for control services: This report describes how the MVP was developed and further enhanced during the project, with an emphasis on how the edgeFLEX platform can interact with grid control services.
- D4.4 – Description of assessment of platform control service performance: This report details how the control services and platform components are assessed, and targets potential actors might be required to integrate the edgeFLEX control services throughout the industry.
- D6.1 – Comparative analysis of potential business impact: This report describes the comparative analysis of edgeFLEX solutions and business models with reference to specific markets as well as exploring possible ways to foster flexibility utilisation.
- D6.2 – Comparative analysis of potential business impact: This report details the changes in the energy sector that drive the need for the evolution of the VPP. It provides an overview of the technical solutions and changes in the mobile communications sector that facilitate the evolution, describes the business models that foster adoption, depicts the

assessments that validate the solutions from an industry perspective and presents a real-world implementation in the operations of a DSO, which can be seen as the blueprint for DSOs for an evolution path towards utilising flexibility.

- D6.3 – Engaging with policy makers, with organisations and experts in regulation and standardisation: This report describes the stakeholder's engagement, exploitation, dissemination, communication, standardisation, and governance activities of the project (including Advisory Board)

2. Trial goals and description of the services

SWW Wunsiedel GmbH is a modern, innovative, and future-oriented municipal utility situated in the city of Wunsiedel in Fichtelgebirge, a region located in north-eastern Bavaria in Upper Franconia. The city is a leader in the field of innovation regarding intelligent solutions and energy management.

The Wunsiedel field trial in edgeFLEX builds of some of the results and outputs of GOFLEX, a previously completed H2020 project, in which consumers were recruited to participate actively in providing energy flexibility. They were equipped with an Energy Management Systems (EMS) and intelligent measuring equipment facilitating automated energy and flexibility trading. This trial promoted citizen and Energy Community participation in the energy supply chain. The GOFLEX system support the integration of local flexibility market (based on GOFLEX trial) with the extended services of edgeFLEX platform, edgePMUs, and market trading platform.

One of the key goals of the edgeFLEX field trial is to enable automated flexibility negotiation and fulfilment. This supports the integration of flexibility market aggregation with fast reaction (dynamics) services for grid balancing (slow dynamics) and management, such as Frequency Control, Inertia Estimation and Voltage Control. Additionally, the trial aims to demonstrate dynamic flexibility offer requesting, offer generation, and offer fulfilment as a proof-of-concept implementation. This implementation integrates the edgeFLEX Platform, Policy Based Grid Management System, and the Market Trading Platform (KIBERnet) which interact with the Energy Management Systems deployed in SWW, to provide the dynamic flexibility.

The following chapter provides insights into the goals of the trial as well as into the fast and slow dynamic services which are deployed at the trial site.

2.1 Goals of the trial

The edgeFLEX SWW trial aims to assess the effectiveness of the edgeFLEX Platform and the flexibility management and market trading platform (developed in WP4), in combination with the real-time power measurement capabilities of the edgePMU and the operation of the ancillary services (developed in WP3). Additionally, it aims to test the communications between these systems and components and evaluate their ability to support the DSO and to support the evolution of VPPs in the context of future grids. Specifically, the scope of the field trial includes:

- Improving the fast dynamics of grid control using the capabilities of the edgePMUs,
- Extending the existing slow dynamics system using the edgePMUs, and
- Integrating the existing slow dynamics system (KIBERnet) into the edgeFLEX platform.

The main objectives of this trial are to:

- Demonstrate the operation of a flexibility market and aggregation platform using the FlexOffer protocol to automatically negotiate with fast dynamics control algorithms for Voltage Control and reactive power deployed on the edge cloud,
- Link new types of edge devices to the edgeFLEX platform, and
- Achieve optimal planning and control of flexibility and edge control, using edgeFLEX components and services for cloud to edge communication.

The trial demonstrates integrated energy trading and grid operation. As the trial operates based on flexibility via the Market Trading Platform, therefore unbundling requirements (i.e., the separation of supply and generation from the operations of system operators), the trial can then be seen as a prototype for future citizen Energy Communities which not only engage with the energy supply chain but also demonstrates new ways to manage subsections of a local grid.

The edgeFLEX Platform and Market Trading Platform have been implemented and tested. Tests of the communications between platform interfaces enabling the interaction between platform components, of the services and of interactions with external systems and entities such as the flexibility providers in the Energy Community using the FlexOffer protocol (defined in WP4) were conducted. Furthermore, the edgeFLEX Policy Based Grid Management system was tested to investigate its usefulness as an energy broker supporting the requesting and provisioning of flexibility on behalf of ancillary services.

Furthermore, the edgePMUs are integrated and linked to existing systems in the SWW infrastructure and to the edgeFLEX Platform components enabling greater grid visibility and thus providing the level of control required for the operation of a power grids which integrates volatile distributed RES energy production assets into its operations.

2.2 Description of the edgeFLEX slow and fast dynamics services

The services in the SWW trial involve energy supply and balancing (slow dynamics) and power grid operation and stability (fast dynamics) as described above in section 2.1.

2.2.1 Slow Dynamics Services

Slow dynamics, in the sense in the edgeFLEX project uses this term, covers the balancing services and normal operational management measures taken by a system operator to maintain the continuous and safe operation of the power grid. The Energy Community concept was implemented in SWW, while functioning as a VPP. The community owned VPP, besides providing a continuous power supply, can also support services for balancing as it can fulfil threshold requirements of 1 MW as set in Germany for participating in energy balancing trading.

The slow dynamic services are locally aggregated and are traded in 15-minute intervals by using the KIBERnet EMS system. In the context of edgeFLEX, the slow dynamics consider the variations of the generation profiles, or the state of charge level of the storage systems installed in the grid. The slow dynamics allow the possibility to apply control actions within a large time interval, and therefore the possibility of providing flexibility requests to KIBERnet and to wait to receive the response. Moreover, the large timescale gives the possibility to use forecast data for load and production values, which are also normally provided for large time intervals, to calculate control output within a future horizon. The edgeFLEX Voltage Control services use the 15 minutes timescale to perform the control of the voltage in distribution grids considering the slow dynamics described here. The slow dynamics aspect is performed with a Model Predictive Control (MPC) algorithm, which allows calculations of the flexibility request generated by the market and integration of the Flexibility Offer (FlexOffer) into the market.

2.2.2 Fast Dynamics Services

Fast dynamics services, in the sense in the edgeFLEX project uses this term, aims to address issues of grid stability and to provide services to optimise power system operations and the stability of the power supply chain. In contrast to slow dynamics, fast dynamics describes fast variations occurring in the electrical grid, due to rapid changes of the conditions in the grid, and for which control services need to be executed to restore grid stability. The control services are the ancillary services mentioned in section 5.4, namely Voltage Control and congestion resolution actions. The reactions to these dynamics directly depend on the measured values, without considering forecast values. The speed of the control actions also depends on the type of electrical quantity or event to be controlled. In the case of the online voltage control, the rate of control considered in edgeFLEX is one minute or less, given that the speed of the control action of the voltage only depends on the reporting rate of the measurement units and on the reaction speed of the assets.

3. Trial preparation

The preparation of the field trial included the following activities:

- The identification of locations for the deployment of measurement equipment,
- The identification of the type of measurement devices required to be installed, followed by
- The collection of data, which was then structured and managed to create a solid foundation for
- The FlexOffer implementation process.

These four main activities are described in this chapter.

3.1 Location selection

The positioning of any measurement device can impact on the quality of the data obtained, therefore the selected locations for installation were chosen carefully based on assessments of their likelihood of providing the optimal measurement data.

Three locations were chosen, on a specific cable of the MV network of SWW, for the installation of edgePMUs. Two edgePMUs were installed at substations at the ends of the cable, and a third in the middle section of the cable. These locations were chosen to enable a high level of transparency on grid events as they host multiple connections for a Factory Energy Management System (FEMS).

In more detail, transformer station “A” operated by SWW serves three FEMS, which are shown in Table 1:

Table 1 – Participating Factory Energy Management System location

Transformer Station	***Location of FEMS***
“A”	SWW building
	Electrician company
	“Haus der Energiezukunft”, exhibition hall for innovative energy concepts
“B”	Buildings yard
“C”	Water pumping station

The three locations identified, and on which the edgePMUs were installed in the order of the time of installations, have the following characteristics:

- Position 1 (edgePMU1): A point on the cable, where a PV plant is installed on the MV feeder directly.
- Position 2 (edgePMU2): At the start of the cable, which is the point of connection between the upstream and the downstream DSO. The measurement of the voltage in this point is relevant since it influences the voltage values for the whole feeder.
- Position 3 (edgePMU3): Another final point on the cable, that includes a substation.

The locations can be seen in Figure 1:

Figure 1 – The locations of the edgePMUs

3.2 Measurement Devices

To obtain measurement readings from the selected locations on the trial, three edgeFLEX edgePMUs were deployed.

The newly developed edgePMU and its communication capabilities require a high-rate of raw data transmission between the acquisition device and edge cloud leveraging wireless connectivity (including 5G) at the medium voltage level.

The edgePMU approach implements the phasor estimation and frequency calculation in a virtual network function procedure. It leverages the results of the NRG-5 project, in which the virtual PMU concept was implemented. The virtualisation of functionality provides great flexibility with regards to implementation and maintenance as well as updating of the algorithms. In fact, the edgePMU software can be easily and quickly remotely updated as needed. The edgePMU can also act as a local phasor data concentrator for different edgePMUs deployed on the field, thus providing the functionality of a concentrator.

edgePMUs can be used to measure electrical quantities from the grid, such as voltage and current (and their products, e.g., power and frequency). The measurements are taken with a timestamp, which are then given as inputs to the services such as voltage control. The edgePMU, takes sampled time-stamped measurements, while processing is done in the edge cloud. The innovative approach of the edgePMU allows DSOs to monitor real-time voltage and current data in a low-cost manner, while the data is being processed on the edgeFLEX platform. The installation of the edgePMU devices has given SWW a higher transparency on grid events, making it far easier to deploy control measures and to enhance it grid operations.

Three edgePMUs were installed as described above to collect measurement data. A dedicated virtual private network has been created to control the edgePMUs remotely. This network is also used to initiate the tests and remotely supervise the devices. A user interface to visualize the status of the installed edgePMUs has been implemented to show a screenshot of the status of one edgePMU. Since each edgePMU is equipped with a GPS receiver, the data received by the devices also reports their locations. This is used to visualize the location and status of all edgePMUs in the location dashboard, as presented in Figure 2. The figure shows the geographical location of the three edgePMUs and their status. In the screenshot presented, the dashboard is displaying an error on one of the devices. In that particular case, there was an issue with the connection of the device to the underlying sensor. Therefore, thanks to the dashboard, the error is geographically identified, which simplifies the management of the installed devices.

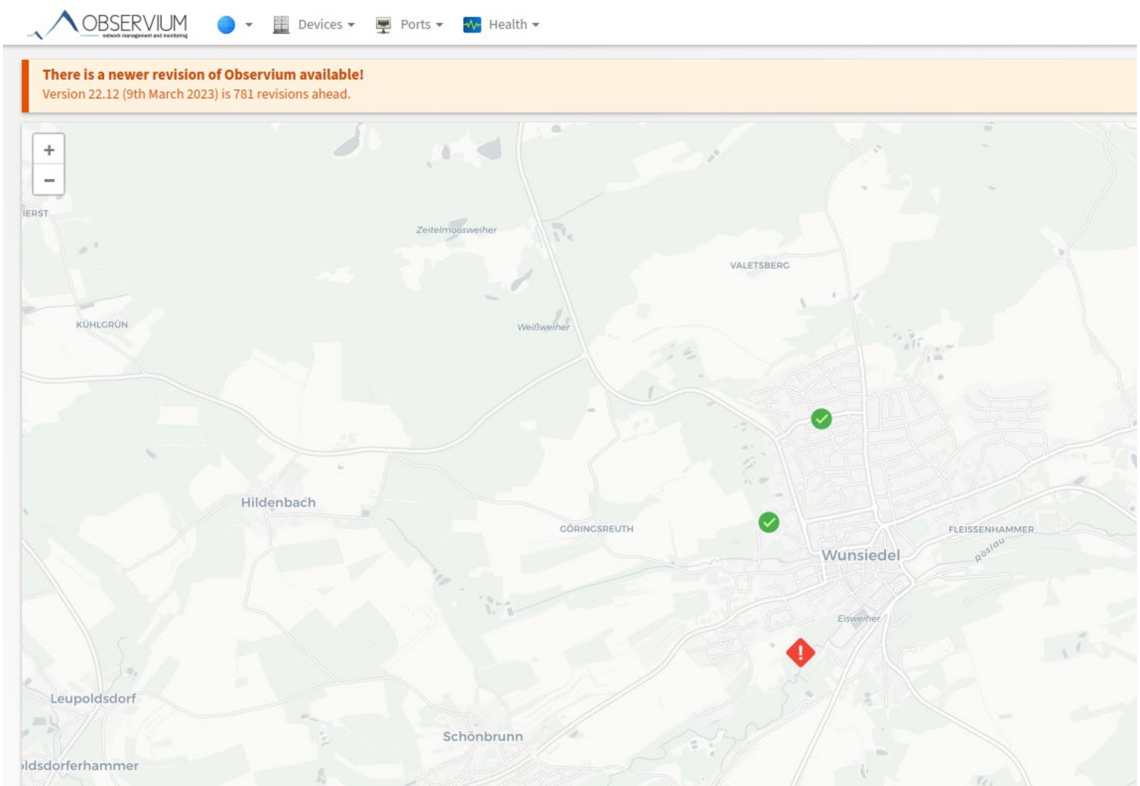


Figure 2 – edgePMU status and location

A second dashboard has been created to visualize real-time data coming from the edgePMUs installed in the grid. The dashboard, based on the Grafana software, is shown in Figure 3, which shows the monitoring of voltage (in magnitude and phase), the frequency and the Rate of Change of Frequency (RoCoF) calculations performed in the cloud, based on the data received.

Figure 3 – Dashboard for the visualization of the edgePMU data

3.3 Data Management

Measurement data obtained from the installed edgePMUs are passed to the interfaces where they are needed. Factory and Home Energy Management Systems, FEMS and HEMS devices respectively, are connected virtually to the KIBERnet interface. KIBERnet is a management tool offering automated control of electrical loads and data monitoring from connected systems.

The FEMS installed within SWW are compatible with the data interfaces implemented in KIBERNet, and additionally, the edgePMUs data streams were integrated into the KIBERNet system. Finally, communication streams were established between KIBERnet, the installed edgePMUs and the edgeFLEX Platform to enable the trial.

3.4 The edgeFLEX “FlexOffer” implementation process

To realise the generation of FlexOffers from the KIBERnet system and their actuation on the grid, several edgeFLEX platform components work in tandem. Specifically, the edgeFLEX databus, Policy Based Grid Management System (PBGM) and voltage control service operating in Model Predictive Control (MPC) mode.

While in operation, the voltage control MPC captures power flow readings based on edgePMU data from the field via KIBERnet, which is passed to the edgeFLEX databus (Figure 4). In this way, the voltage control service is constantly monitoring the power flow readings. When an over or under voltage measurement is captured, a request is made to the PBGM system to request flexibility on behalf of the voltage control service, which is enabled through KIBERnet.

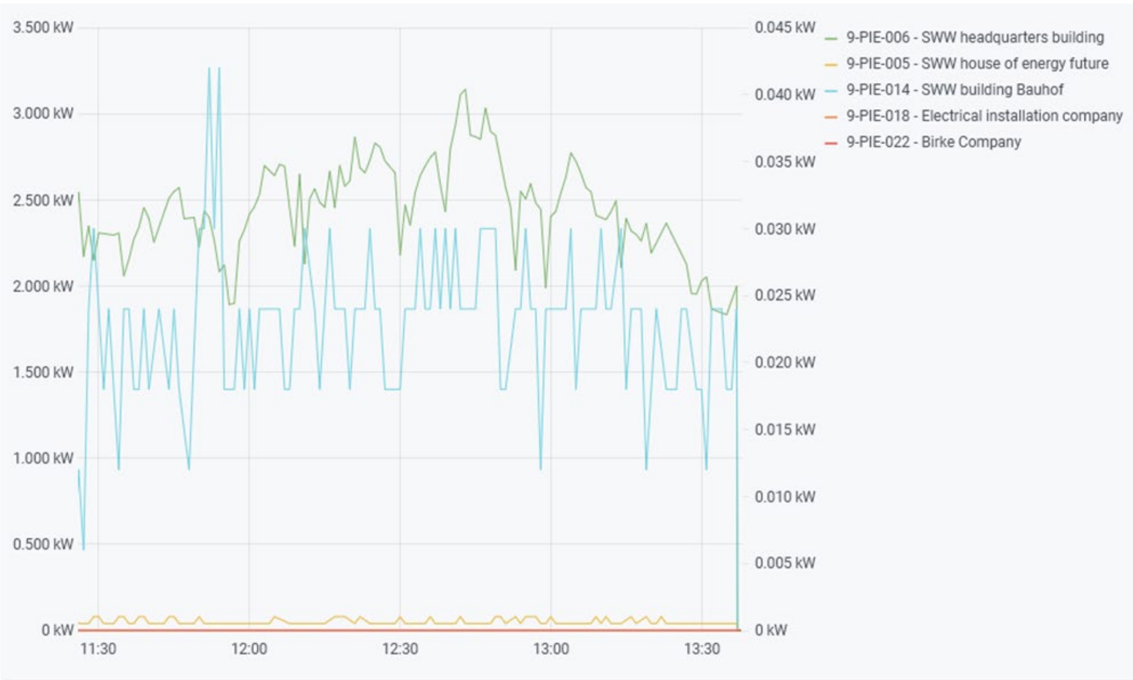


Figure 4 – Power measurement on the edgeFLEX platform

The bounds and details of the flex request generated by the PBGM system to KIBERnet is controlled via user generated policies. Each MPC enabled node has a distinct FlexOffer template in place, which are defined and can be adjusted dynamically by the user via the PBGM admin interface as presented in Figure 5.

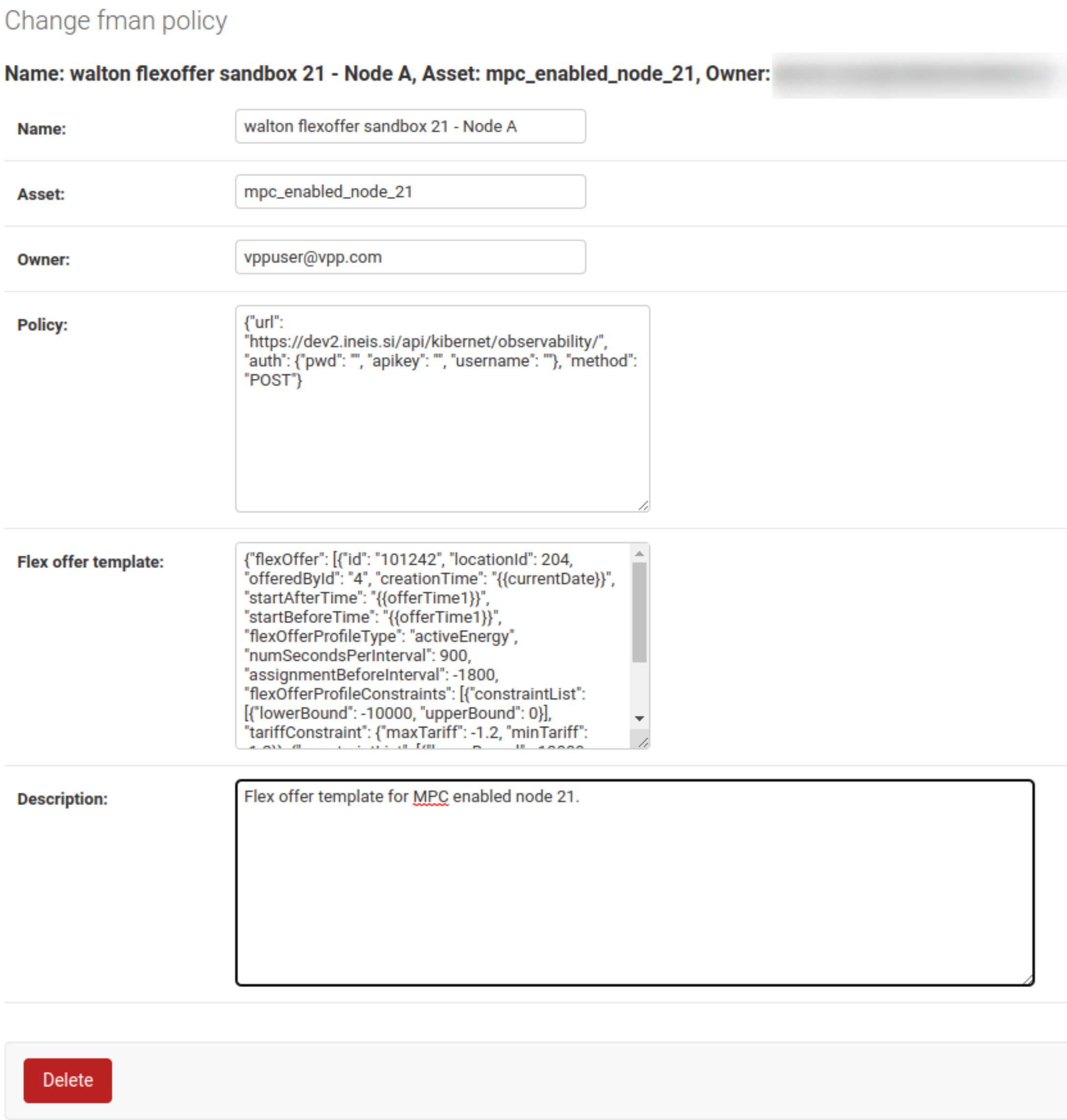


Figure 5 – PBGM FlexOffer template utilised in generation of FlexOffer

As the generation of a FlexOffer is not immediate, it is necessary to poll KIBERnet periodically until a FlexOffer is generated and returned. To enable this, on the initial request for flexibility, KIBERnet returns a “heartbeat” containing relevant details to differentiate unique FlexOffer requests. This heartbeat is returned to the voltage control service by the PBGM system, after which the voltage control service makes the periodic requests to KIBERnet directly with this heartbeat, the FlexOffer is generated and returned to the voltage control service by KIBERnet. The returned FlexOffer is processed by the voltage control service at which point it actuates on the active grid nodes in response. This interaction between the relevant components is illustrated in Figure 6.

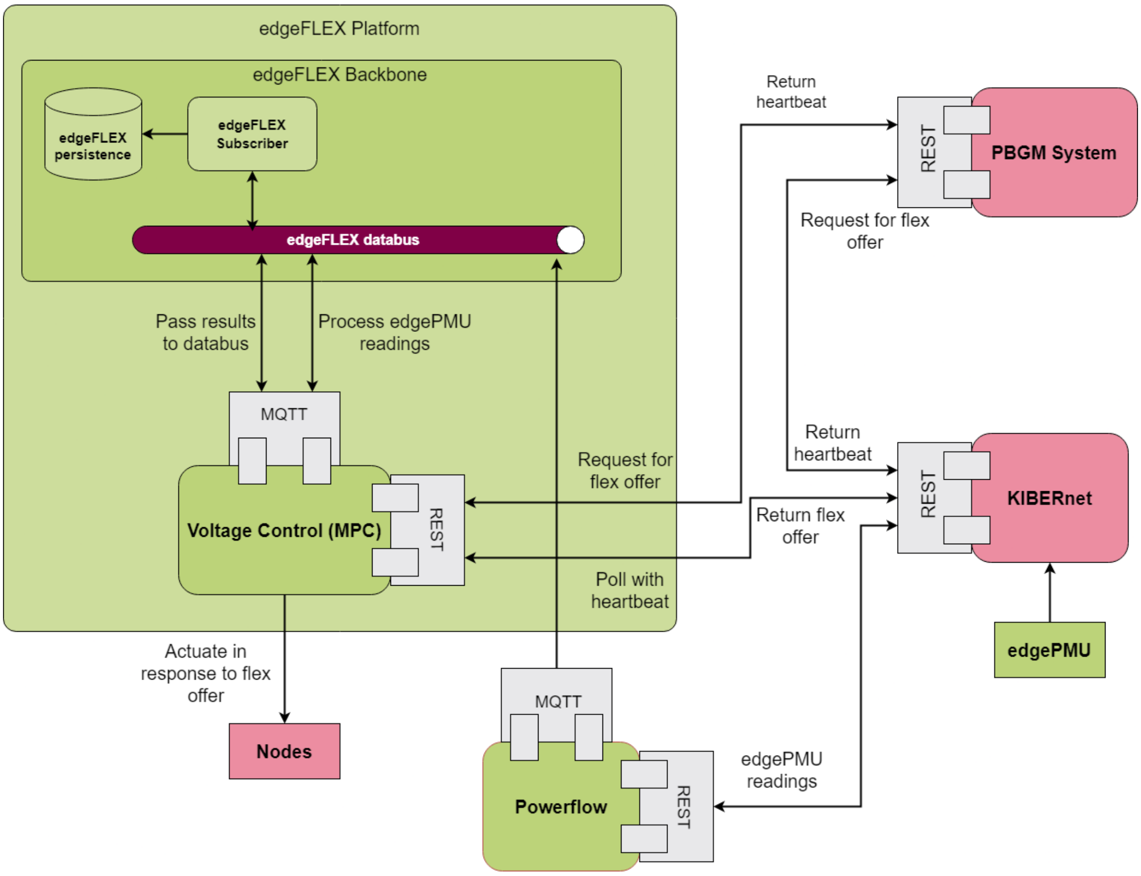


Figure 6 – Flex generation interaction

3.5 Conclusions of Chapter 3

The three edgePMUs were strategically positioned on one cable, which was chosen for its connections to existing FEMS which are used in the trial. As the edgePMUs were placed at the beginning, middle and end of a cable, including substations, existing infrastructure was leveraged.

Through the edgePMUs it is possible to make phasor estimation and flexibility calculation virtually and to monitor real-time data related to voltage and current. To enable easier interpretation of the data a visualization dashboard was developed and implemented to provide graphs of the real-time measurements from the field. In addition, a device management dashboard was developed to provide information related to edgePMU location and status.

Data transmission is achieved via the KIBERnet system and through the use of outward facing interfaces, to the edgeFLEX Platform components and services. By enabling a data stream to KIBERnet, grid events such as an over voltage can be identified and FlexOffers generated in response to resolve the event and to ensure the stability of the grid.

4. Accompanying actions of the field trial for the implementation of the edgeFLEX solution

In order to fully achieve the goals and objectives of the trial, further actions were required. Firstly, the data streams enabling data collection and communication between edgeFLEX services, components and platforms need to be stable, fast and reliable. Access to 5G communications ensure these demands and so efforts were made to leverage this capability if it was available in the trial location. Secondly, the establishment of the Energy Community demanded user engagement strategies and customer acquisition.

These actions are explained in greater detail in the following chapter.

4.1 5G Communication Infrastructure in Wunsiedel

As part of the work to ensure the best framing possible for implementing the edgeFLEX solution in the field trial, measures were taken to promote the integration of 5G communication technologies to allow a faster and more reliable way to transmit data and enable system communications.

Unfortunately, at the time of the trial, despite the best efforts of the consortium to get public network operators to provide 5G coverage in the area, only 4G+ communications were available in the Wunsiedel area. Due to the area's small size, it seems that it is not yet a priority area for coverage for public operators because of the need for network communication infrastructure investment and the low revenue that the increased coverage would generate.

The edgeFLEX consortium has supported measures to promote the expansion of better communication: The so-called 5G Corridor Munich – Prague was initiated in 2020. The goals of this programme include strengthening cross-border cooperation in the development of common application scenarios for high-speed cellular networks and as part of the Connecting Europe Facility to implement a trans-European network for energy policy, implementation of joint bilateral projects, particularly in scientific, technological and economic cooperation in the application areas of eHealth, Industry 4.0, Connected Mobility and Smart Regions as well as creation of a 5G corridor between Munich and Prague as an active part of the "Connecting Europe" Facility (CEF) of the EU Commission. Although funds were applied for this programme, the constant change in the consortium submitting the proposal, made it difficult to make substantial progress. However, an application was eventually submitted.

Furthermore, an application for InterReg Europe, an initiative programme for the collaboration between governing entities across Europe, was submitted in 2022 but was unfortunately rejected. An application was also submitted to the Smart Regions programme, but tooling was financially not strong enough to support changes. The aim of this programme is fostering knowledge-exchange and project initiation across borders. SWW takes part in a green infrastructure project called "Green Steer Europe", which had the objective of supporting the energy transition to a climate-neutral central Europe via a newly developed planning framework.

A cross-border association, Digital Space Main-Danube-Vltava, is in the process of being founded and may also serve for fund raising at a later stage, but effects at the Wunsiedel location are only to be expected after the end of the project.

A summary of the considerable efforts made by the consortium to promote 5G coverage is presented in Figure 7.

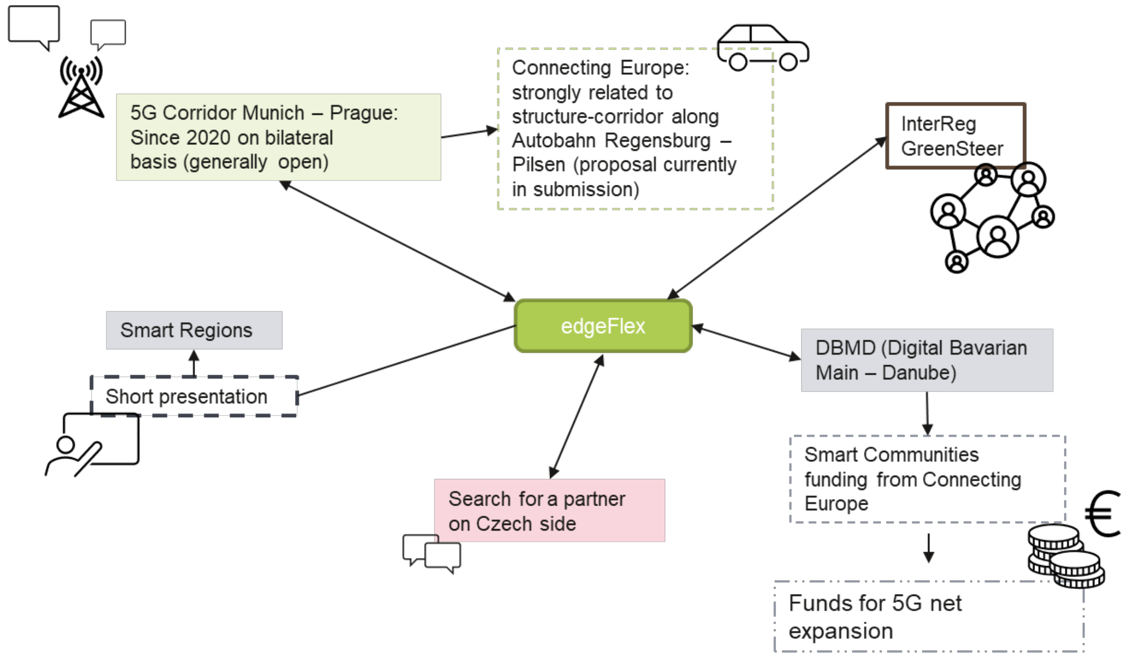


Figure 7 – SWW 5G integration plan

4.2 User Engagement

User engagement is a crucial part for achieving grid operation efficiency. The benefits which can be gained with such an approach combine all three pillars of sustainability, namely economic, environmental, and societal. This is due to the allocation of resources and usage, which involves fewer losses of power generation, and supporting community empowerment.

SWW has started promoting this approach, beginning with the GOFLEX project, whereby consumers and assets owners, with the aid of various incentive methods, were recruited and equipped with new EMS. Design thinking workshops were conducted and newspaper articles were published to engage users. These actions assisted in exploiting the willingness of users to participate in the energy supply chain to the benefit of all involved parties, which encouraged some users to share their thoughts and ideas, provided an example of engagement of other potential users. This enabled SWW to co-create the to-be-established flexibility system leading to high acceptance of the offers to join, as customers were involved from the very beginning.

The different assets installed in the jurisdiction of SWW's grid were properly identified. This allowed consumers owning assets to become prosumers and participate in the field trial enabling the engagement of a prototype Energy Community in the edgeFLEX SWW field trial. Based on the capability of the flexibility trading infrastructure, SWW, alongside other edgeFLEX consortium members, were able to exploit the interest of local stakeholders to participate. By joining this scheme, participants could join the local flexibility market and generate additional income. In return, SWW provided energy in times of high demand, when the users could not cover their demand on their own, while the energy surplus of these prosumers in times of low demand was sold to SWW. This approach was offered to both homeowners and industrial customers.

The edgeFLEX field trial started after the GOFLEX trial ended. GOFLEX had approached the users and involved them in the earlier GOFLEX trial, so the interest of participants to continue taking part in the energy supply system was already there as a basis for edgeFLEX work. In addition, the importance of user engagement was identified in the early stages of the edgeFLEX project. This has led to the outcome that SWW managed to keep all customers on board until they could participate in the edgeFLEX field trial.

Throughout the project SWW was and still is engaged in promoting the concept of citizen participation through design thinking and co-creation workshops and workshops for stakeholder engagement. It was not enough for the municipal energy service provider to simply inform the citizens about the possibility for them to join the new edgeFLEX trial. The previous GOFLEX system was good but could be improved since it was neither perfect nor state-of-the-art anymore. Therefore, SWW targeted the implementation of the Energy Community strongly. Despite the regulatory hurdles, SWW managed to create the Energy Community in the form of a new balancing group. SWW was able to successfully maintain a number of customers to engage in the new edgeFLEX project, and to acquire additional ones. The balancing group has been prepared and ready to go to be established as a real Energy Community as soon as German legislation allows it. This was a great step forwards towards establishing a Peer-to-Peer (P2P) trading scheme and improved services in the context of the fast and slow dynamics in the SWW trial. Further, SWW is working to understand how DSOs can be involved in the edgeFLEX ambition which is strongly focused on the customer engagement and new trading schemes.

In addition, SWW has already begun integrating a new initiative, complementary to the edgeFLEX solution, which is called the “Zukunftskraftwerk” (which translates to English as the “Future Power Plant”), which will be integrated with the local Energy Community. This approach aims to establish individual “energy cells”, (one for each participating household) which will act as individual power plants equipped with a storage capability. These cells will be aggregated by the DSO or an aggregation entity via IoT platforms and will consume their own generation of energy, to the extent that it is possible, and trade flexibility among the cells. The cells will offer flexibility services as an aggregated entity (VPP) to other parts of the grid – local, regional, and national levels, tackling fast and slow dynamics issues and contributing extra flexibility to the grid.

The positive attitude and acceptance of customers of the proposed solutions are of high value in relation to the implementation of the exploitation plans of the project partners of edgeFLEX, as well as the realisation of the project itself. Without customer engagement the testing is impossible.

To further positive attitudes among customers, investigations were conducted to identify:

The benefits for relevant stakeholders,

- the barriers they face, as well as
- their level of their knowledge regarding energy provision and supply, and
- the level of involvement of the community were identified.

The investigation regarding acceptance levels and potentials was carried out in three phases:

- **Phase 1** involved data collection, potential participants and assets already implemented were identified and the Energy Community roles were defined.
- **Phase 2**, the engagement strategy was determined. This was done by means of workshops, personal interviews and incentives offer as illustrated in Figure 8.
- **Phase 3** focused on future engagement and included ensuring of involvement in the Energy Community, increasing the willingness to participate in future projects and guaranteeing continuous communication and contact with customers. These measures include “word-of-mouth” marketing, sharing project outcomes, enhancing engagement strategies and introducing the potentials, advantages and possibilities of utilizing the edgeFLEX platform developed within the edgeFLEX project.

Figure 8 – Customer Engagement Strategy

The survey results showed that they had basic knowledge of the issues and were willing to learn more. They were also very satisfied by the outcomes and benefits which resulted from the Energy Community offer.

Citizen participation enhances SWW's existing strategy for grid strengthening and optimization. This strategy also includes the physical improvement of power grid assets, (e.g., investments in cables and distribution stations), which will result in better energy and asset management by SWW, while improving the transparency of the distribution grid enabling SWW to better identify problems and to resolve them faster at the local level reducing the problems of the Transmission System Operators in maintaining grid stability. In this regard, both storage buffers and innovative business plans have been deployed alongside the edgeFLEX platform and services implementing the VPP concepts developed within the project.

Those measures have already led to an increased potential for the provision of flexibility services, through the Energy Community and they will eventually enable a higher penetration rate for renewable energy resources in the area. In general, SWW perceives customer engagement as an empowerment of the citizens to generate energy and to sell it in a more flexibility on societally conscious manner. Customers are enabled to become more autonomous and independent when it comes to energy consumption. These measures also contribute to building future energy systems that are more customer-oriented and transparent.

In addition, further observations have been made, as follows:

- Energy Communities and citizen participation enable a high local potential for flexibility services,
- Cost-efficiency, while ensuring energy stability and security with low-carbon and high sustainability, are strong incentives motivating citizens to participate, and
- Already engaged customers tend to stay engaged, and even promote ideas for developing and implementing new energy solutions to new potential customers, further increasing the impact of the joint efforts of participants.

Although innovators and early adopter participants of the new concepts enjoy the possibility of establishing networking among the members, new customers profit from this network as well. Customer acquisition can be undertaken easily as the existing networking among members provides an incentive by itself for new members to join. Additionally, proof of concept implementations of some newer innovative solutions are already available and are considered as lucrative by members, and experience has shown that the existing customers involved in the Energy Community promote these benefits to potential new members.

4.3 Energy Community support for solving grid imbalances and other issues

The concept of the EC refers to wide range of roles and responsibilities, in which citizens and other stakeholders can undertake measures and actions contributing to power grid and energy supply operations. In this type of constellation peers within the EC can exchange energy among themselves in a peer-to-peer trading scheme. They can also exchange energy with external participants when external connection to other distribution grids already exists with the local DSO infrastructure, as illustrated in Figure 9.

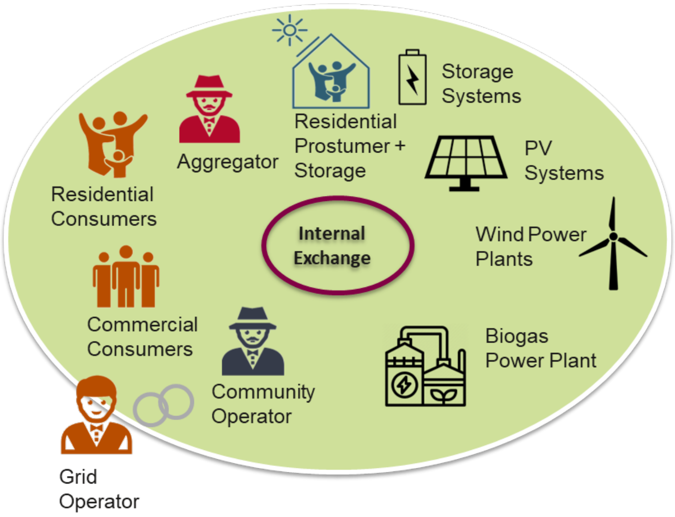


Figure 9 – An example of an Energy Community constellation

Community-owned models for generating energy exist in different forms and vary from renewable energy-based generation systems through to district heating and storage systems[1]. The community-owned electricity generation models can be regarded as a VPP for a range of purposes, including physical balancing. Physical balancing measures are the most important task of a grid operator, as consumption and production must be kept in balance in order for the system to operate without interferences. The EC is a type of citizen (or user) participation. In essence, the EC will consume locally generated energy and only in the case of a surplus or deficit of power will the energy be shifted in or out of the EC, respectively (as illustrated in Figure 10). Should the EC have a sufficient numbers of energy generation systems as members, either with or without storage, it can provide services to the grid operator improving the viability of grid operations. The electrical energy provided by the EC, acting as a VPP, can be bought and sold on the different available markets. It is also possible to create a biliteral agreement to supplying directly to the DSO and to thus offer a constant power supply.

Therefore, an EC acting as VPP can provide not only services for DSO operations under normal conditions, offering long-term planning possibilities to the DSO through slow dynamic services, but also can provide ancillary services as fast dynamics services to counteract events in the power network which need to be urgently addressed. In the scope of the edgeFLEX project, these services are flexibility-based.

Depending on the amount of power available, an EC can provide primary frequency control services to the grid. In Germany, a minimum of 1 MW must be always available if an EC is to offer primary frequency control services. In addition, the EC can provide voltage control and reactive power compensation services, based on its proximity to the grid elements as well as its ability to offer flexibility services to address congestion management issues.

[1] IRENA (2020), *Innovation landscape brief: Community-ownership models*, International Renewable Energy Agency, Abu Dhabi.

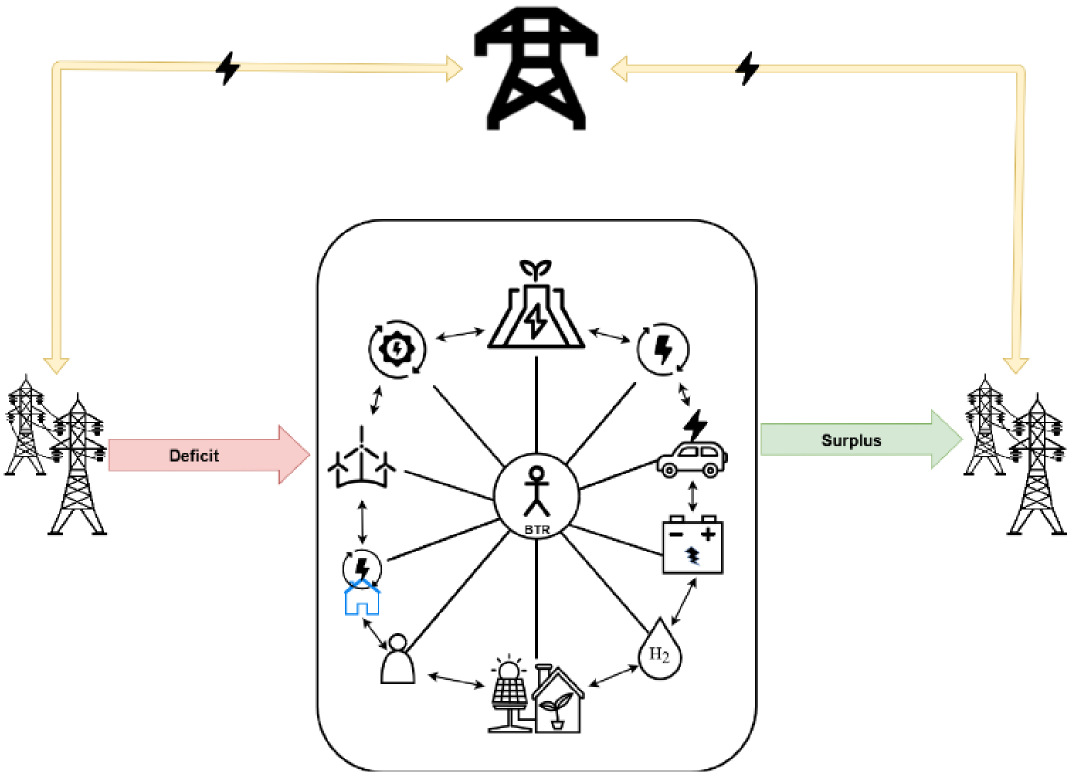


Figure 10 – EC internal and external relationship

The DSO, as a flexibility aggregator, has an important role to play in coordinating the EC and its assets. Using the edgePMU to provide voltage measurements and aggregating and matching flexibility demands to the flexibility offers of the EC, the DSO can coordinate the flexibility aggregation via KIBERnet which communicates with the edgeFLEX platform as shown in Figure 11. It is possible for a DSO to build up those assets using contracting models, but the EC on its own, also has fundraising capabilities available through its members as illustrated in Figure 10below.

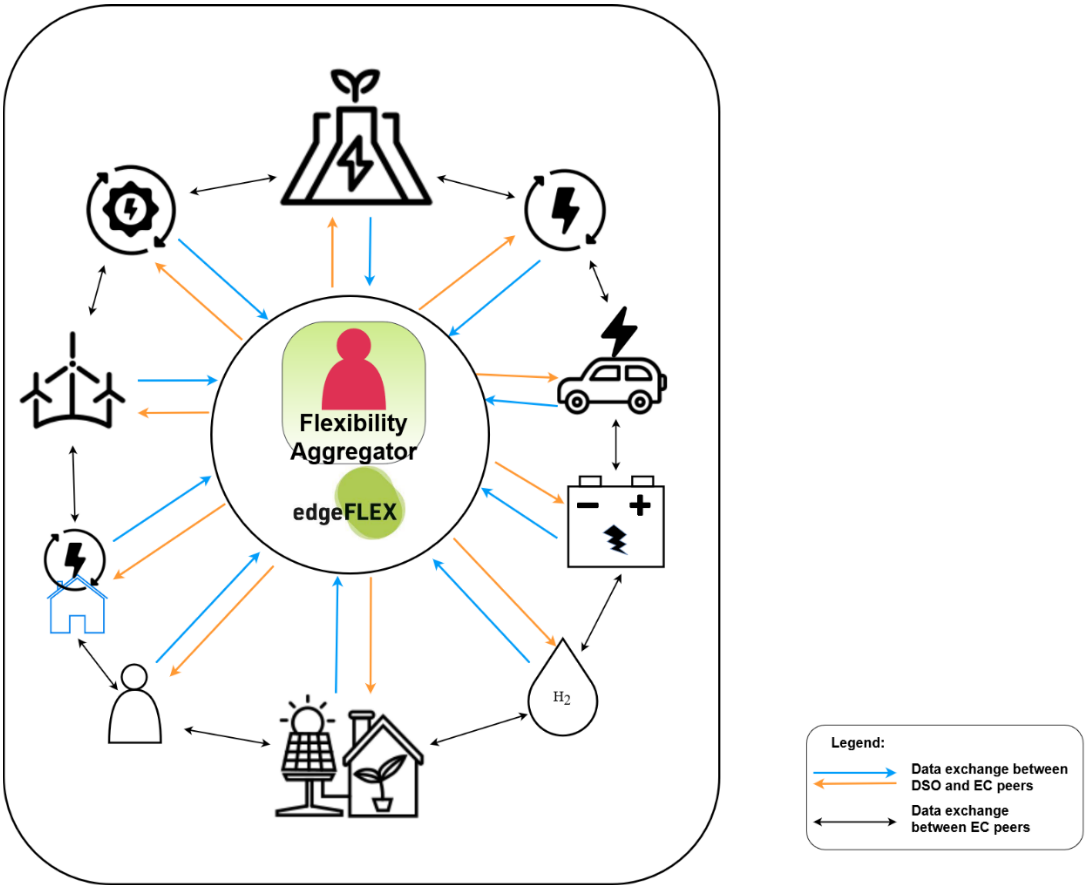


Figure 11 – The role of the DSO as a Flexibility Aggregator

4.4 Conclusions of Chapter 4

To provide the best framing for the edgeFLEX SWW trial, the availability of 5G in the trial site area was desired. To support this goal, efforts were made to push the expansion of 5G in the Wunsiedel locality. These actions covered, for example, the 5G Corridor Munich – Prague. Unfortunately, this effort was not successful. A further effort, the Interreg Europe project Green Steer, which was envisioned by SWW and other partners, was also not accepted. Lastly, SWW founded an association called Digital Space Main-Danube-Vltava and this organisation is now promoting the need for 5G coverage in the Wunsiedel area as part of the Main-Danube-Vltava region.

Due to the efforts made by SWW in engaging with customers, many customers decided to participate in the edgeFLEX project. It was therefore possible for SWW to extend the results of previous projects to enable the edgeFLEX SWW trial. This led to the preparation of the Energy Community by creating a new balancing group. This important preparatory step will help to rapidly convert the balancing group to an EC, as soon as soon as the legislation is in place in Germany to allow this to happen.

The customer engagement efforts of edgeFLEX showed that consumers were willing to learn more about flexibility trading and about the EC and that they were satisfied with the outcomes of the project(s) so far. Lastly, the participation of customers has a positive impact on the grid in relation to its optimisation, strengthening and transparency. SWW discovered, that user engagement provided flexibility and cost-efficiency regarding grid operation. Additionally, customers tend to show continuous engagement once they get involved.

5. Description of the business-focused approach "VPP – SWW-all-in"

In order to realise the proposed solution, SWW applies an "all-in" principle in which SWW assumes several roles, acting as DSO, retailer, aggregator and RES owner, and can thereby control the slow and fast dynamic services as illustrated in Figure 12. This ensures that SWW can oversee all processes of the power supply scheme while also including citizen participation in the form of an EC and being itself an active actor on the energy exchange markets.

This section describes the actions SWW has undertaken to become a more reliable energy provider, including the business approach used to realise this goal. The roles are described in sections 5.1-5.4, whereas the business approach is described in section 5.5.

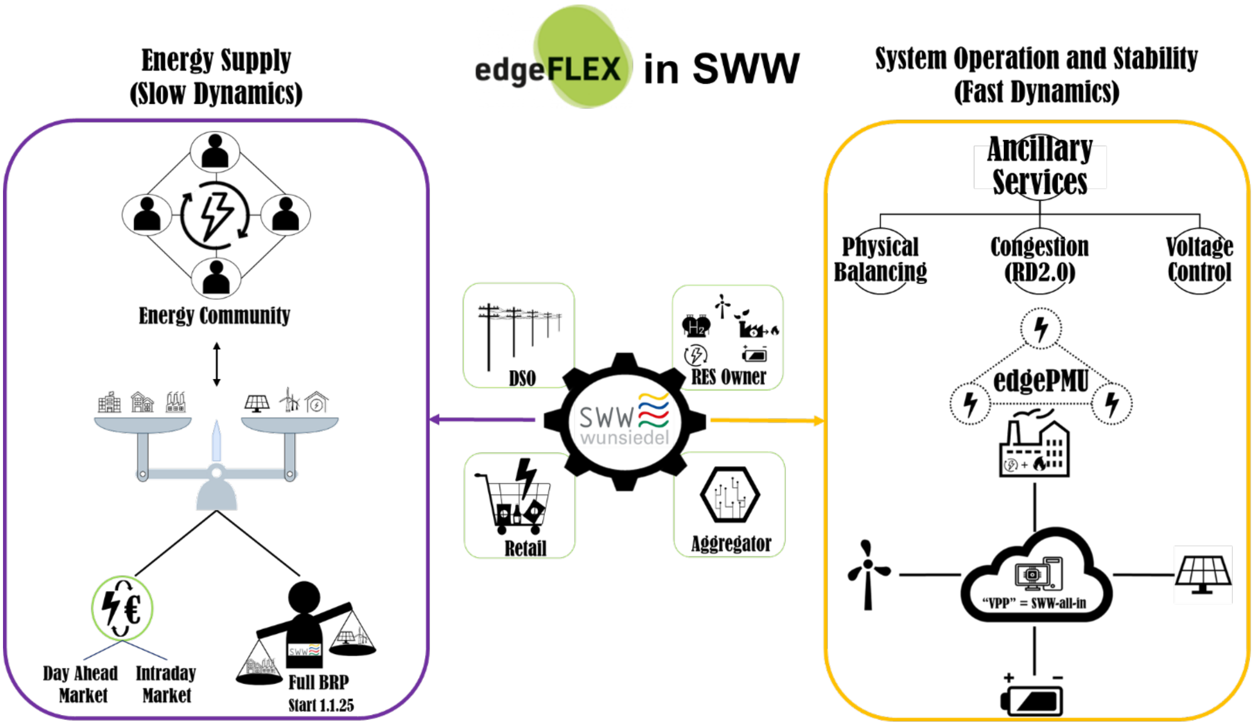


Figure 12 – The SWW "all-in-one" solution in which SWW takes on many roles

5.1 Energy Retailer

Uniper is the service provider responsible for balancing activities in the county of Wunsiedel. SWW fulfills the role of a retailer by purchasing energy directly from Uniper.

SWW applies a direct marketing model. Within the framework of this model, energy is purchased directly from prosumers, who are compensated in accordance with a remuneration agreement, as specified in the German Renewable Act (EEG). The SWW balancing group purchases energy generated by SWW (i.e., wind turbines, PV and CHPs) to be sold via the local energy project named "Fichtelgebirgsstrom" (which can be translated into English as "Green electricity from the region, communal and transparent initiative in Wunsiedel").

5.2 Local Flexibility Aggregation

Participating domestic and industrial prosumers were provided with Home Energy Management Systems (HEMS) and Factory Energy Management Systems (FEMS) respectively. Within the scope of edgeFLEX, SWW takes on the role of local flexibility aggregator which enables the participants to interact with the local flexibility market... This provides the participants with the option of generating additional income by selling their surplus energy to SWW in times of low demand in their own households or businesses, or to purchase energy in times of high demand in their own household or business. In addition, all consumers offering flexibility can trade their flexibility directly with SWW (acting as an aggregator) or they can have the opportunity to offer it directly to the local flexibility trading platform if the flexibility they offer is large enough.

5.3 RES asset owner and operator

SWW owns and operates several distributed RES assets and trades the energy generated from those assets via Lumenaza. The assets owned by SWW are a wood-pellet CHP, a wood gasifier, several PV arrays, wind turbines and batteries. The total combined capacity of those assets is 48 MW. Lumenaza is a Balance Responsible Party (BRP) specialised in RES and trading supply via the local German market bonus scheme (a remuneration model in a subsidised direct marketing under the Renewable Energy Sources Act) and in accordance with the EEG remuneration framework. By assuming the role of a DSO in the edgeFLEX field trial, SWW is supporting the control and management of both slow and fast dynamic services, thereby enabling their testing and validation on the trial site grid.

5.4 Business approach

The proliferation of additional RES in the Wunsiedel distribution grid results in a greater need for SWW to ensure the effective operation of both the grid and the energy supply chain. Issues arising from RES integration, such as congestion control and voltage balancing needs in the local grid, must be resolved locally by the System Operator (which is SWW). Flexibility capabilities describe the degree to which a system can react to changes, both anticipated or not, in addition to the reaction speed and duration of actions to correct changes. Flexibility capabilities are the biggest enablers for optimizing grid operations and ensuring a secure energy supply. Hence, the key task of SWW is to ensure that the physical consumption and production are kept within the operational boundaries of the local power system.

The physical balancing of the grid is a vital service, as it involves ensuring grid frequency remains within acceptable boundaries and, as such, both the generation and consumption of supply must be kept in balance. As a Balance Responsible Party, SWW takes responsibility for imbalances occurring in the Wunsiedel electricity grid. This responsibility is in accordance with the objectives as laid out in the guidelines on electricity balancing[2] to support balancing the grid efficiently, which also incentivizes market participants. It also extends to cover SWWs control capabilities in the local energy grid. Furthermore, assuming the role of the BRP on the local grid opens the possibility to SWW to participate in further power exchange markets. In relation to the edgeFLEX SWW field trials, flexibility is managed to provision and operate such control and balancing services. Starting from 2025 onwards, SWW aims to begin operating as a full BRP, and therefore will control all services internally, including ancillary services.

SWW will also assume the role of ancillary services provision and administration, in particular for Voltage Control and congestion management systems. Ancillary services are those provided by either energy generation systems or by the System Operators themselves, to System Operators at different levels of the power grid, with an aim of ensuring power supply operations are within predefined and acceptable limits. In relation to the edgeFLEX SWW field trials, the scope of the ancillary services are as follows:

- Voltage control for maintaining voltage levels at acceptable boundaries for system operation, and
- The extension of redispatch measures (“Redispatch 2.0”) as a service for congestion management through managing flexible assets to relieve grid bottlenecks by shifting loads.

[2] COMMISSION REGULATION (EU) 2017/2195 of 23 November 2017 establishing a guideline on electricity balancing (Text with EEA relevance)

From a technical perspective, SWW is responsible for all services to be provisioned, and in return acts as the Balancing Group Manager (BGM) for Wunsiedel, together with an energy market broker, which will remunerate SWW. This remuneration on provisioned services is divided into intraday and day-ahead markets, depending on the type of service and timeline of planning and provisioning as illustrated in Figure 13.

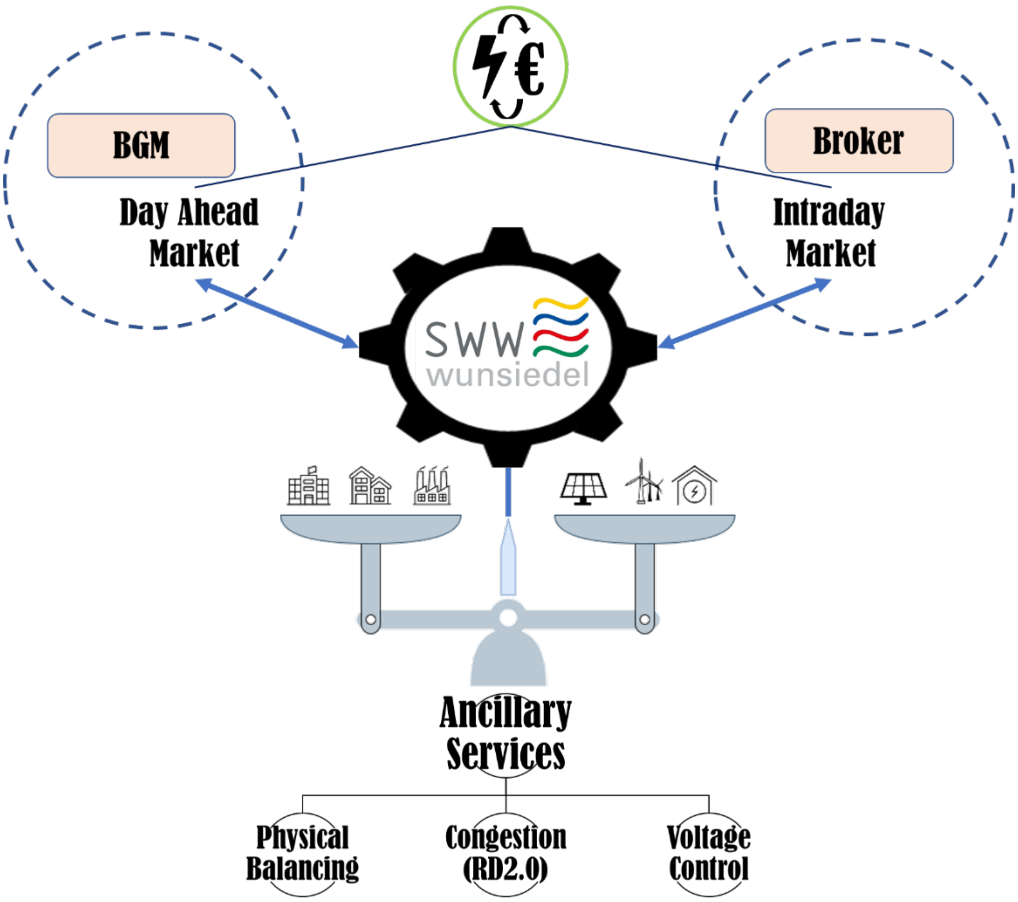


Figure 13 – Business approach scheme

There are a number of advantages to be considered when a Virtual Power Plant (VPP), managing multiple generation and flexible assets, can be used as a service provider to support energy supply and grid stability. From a monetary perspective, leveraging a VPP based approach reduces excess expenditures and from a non-monetary viewpoint, it allows optimal allocation of power resources and community empowerment and therefore increases the willingness of users to participate in the power system.

This business approach aims at enabling SWW, as a DSO with additional responsibility, to be able to control the grid more efficiently, while advancing towards implementing the edgeFLEX VPP 2.0 model. The so-called Future Power Plants ("Zukunftskraftwerk"), mentioned in section 4.2 are planned to be implemented as part of this approach and will be combined with the integration of the local Energy Community.

5.5 Conclusions of Chapter 5

The all-in principle of SWW means that SWW takes responsibility for all power supply aspects and responsibilities. As a DSO, it aims to increase RES integration while meeting requirements for effective and secure grid operation. Voltage control and congestion issues therefore need to be resolved locally by the municipal service provider. This is necessary, as the grid frequency needs to be kept within defined boundaries to ensure the stability and security of the grid. Therefore, SWW aims, in its business approach, to provide ancillary services regarding voltage control and congestion. Additionally, the business approach empowers SWW to better and more efficiently control the grid, while at the same time proceeding towards implementing the edgeFLEX VPP 2.0 model.

6. Description of edgeFLEX SWW field trial tests and results

This section describes the tests conducted in the SWW trial in detail as well as their results. These tests investigate fast dynamic and slow dynamic services via both a voltage control scheme and via the EC acting as a VPP. The aim of this section is to describe how voltage deviations can be managed using flexibility in a real-time event, in which the EC, taking on the role of a VPP, provides flexibility for grid operations under normal conditions. Amongst other methods, voltage deviations are managed by using the ability to plan the amount of power needed to operate the power network and satisfy the likely demand for power.

6.1 Voltage Control test infrastructure

As described in Section 2.2, the voltage control algorithms developed in edgeFLEX are applied for both slow and fast dynamics. The voltage control developed for the fast dynamics is the online control, described in D1.2, which consists in the direct control of the controllable assets to solve rapid voltage variations in the grid. Conversely, the voltage control developed for the slow dynamics is MPC (model predictive control) control, which is interfaced with KIBERnet to provide flexibility offers.

To create a FlexOffer to compensate for voltage violations, the voltage measurement values are monitored using the edgePMU devices. The optimization algorithm is applied to this data flow, for the purpose of restoring the voltage levels, while minimizing the inconvenience for the customers.

The objective of this voltage control function is not to reduce overall losses or congestion, but only to minimize the amount of power required to be injected or absorbed by the assets to solve the voltage issue. This has the advantage that customers are requested to provide only the minimum amount of flexibility to support the grid, meaning that their remaining flexibility can be used for other purposes. Once the optimization issues have been resolved, the amount of power required for the assets is defined and converted into energy flexibility in a 15-minute time interval.

The slow dynamics control is performed using a Model Predictive Control algorithm, which enables the calculation of the flexibility request to be generated by the market and the integration of the FlexOffer into the market. If the flexibility request cannot completely match the offer, a control action to control the DSO's assets is then performed in a fast dynamics action manner. As no directly controllable devices were available on the field, this was performed as a simulation. The objective was to restore the voltage levels to be within the limit values. In this way, the trial combines both live and simulated elements by leveraging real-time data from the field to simulate a realistic grid scenario (over voltage) and engages flexibility with the market to generate FlexOffers from real prosumers.

The complete description of the various interfaces and data flows is presented in Figure 14, in which the schematic of the distribution feeder, on the left, shows the position of the three installed edgePMUs (in red), which are also the positions of the three controllable devices. The measured data is sent to KIBERnet and then transmitted to the edgeFLEX platform. There, the voltage control algorithm is run and the resulting FlexOffer is sent to KIBERnet. After the internal calculation, KIBERnet provides the response to the edgeFLEX platform, and the control set-points are applied.

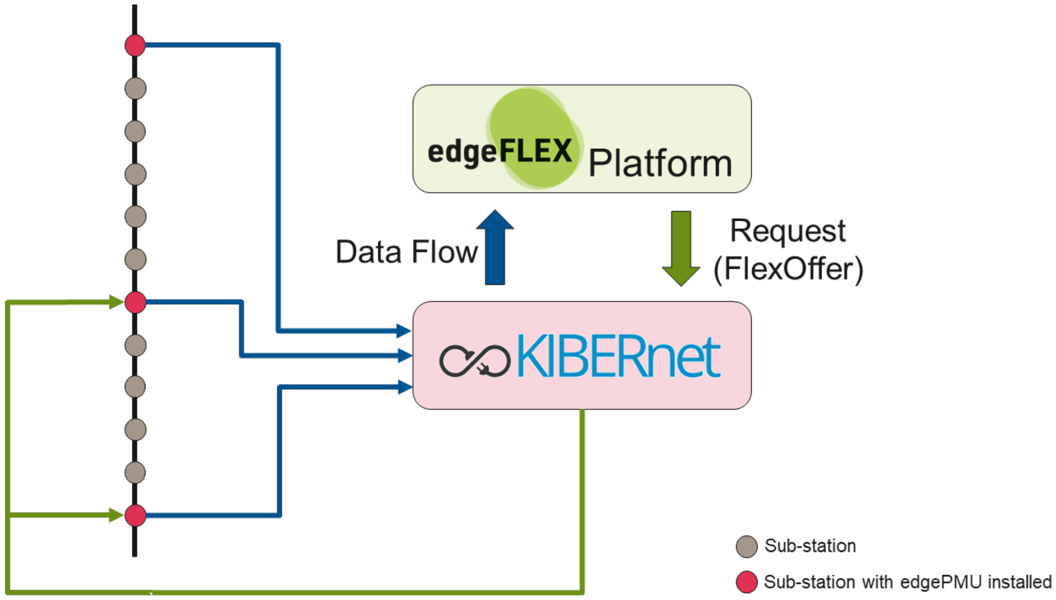


Figure 14 – Flexibility offers generation path

The purpose of the Voltage Control test is to demonstrate how intelligent ancillary services, in combination with engaging the EC, can be leveraged to solve balancing issues locally on the grid, and therefore support the evolution of the VPP towards offering more flexibility to the grid. To achieve this, the trial uses the scenario of an over voltage event to demonstrate the capabilities of the Voltage Control service, in combination with the edgeFLEX Platform, PBGM system and the KIBERnet market platform, to engage with the energy community to request flexibility with the aim of mitigating this event in an automated and dynamic fashion.

The trial leverages a combination of simulated and real-time elements. Specifically, the over voltage event is simulated using a powerflow software module which takes live edgePMU readings to generate an over voltage event. In addition, the Voltage Control service actuates on simulated nodes to resolve the over voltage event generated by the power flow module. In this way, while the event and actuated nodes are simulated, they are interacting with real-time data from the field and requesting flexibility from real prosumers on the grid through live systems deployed in the field, hereby demonstrating how these systems interact in response to grid events. The outputs of this trial are visualised via the edgeFLEX visualisation service, which captures edgePMU data from the field as presented in Figure 15.

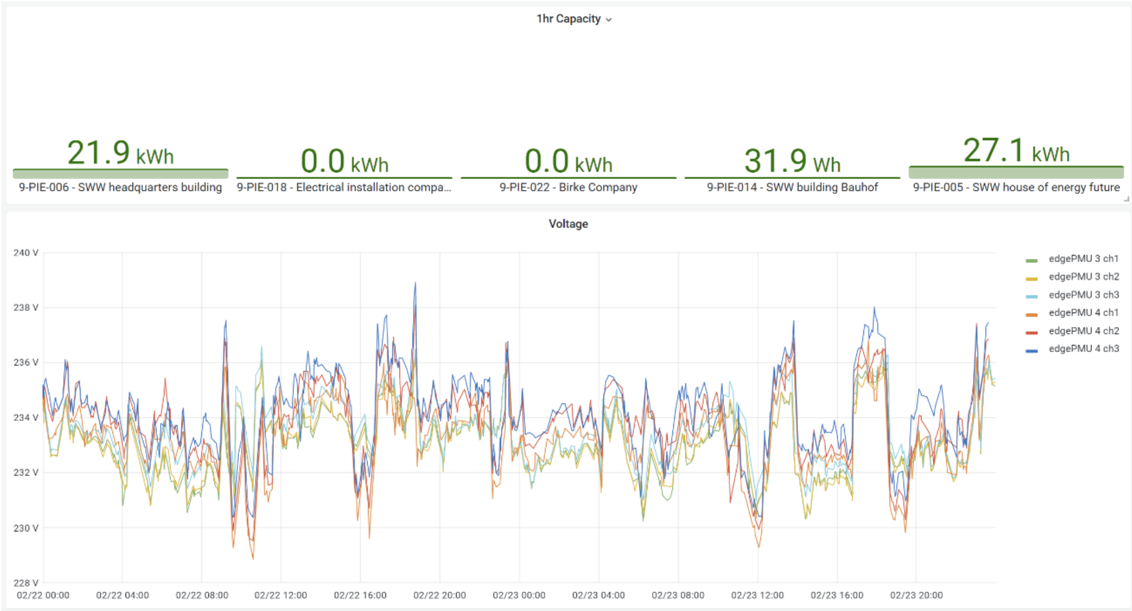


Figure 15 – edgePMU Voltage Visualisation

This test leverages the capabilities of the edgeFLEX Platform and its interfaces, to enable communication between the Voltage Control service, the PBGM system, the Market Platform (KIBERnet) and the energy community. In operation, the powerflow simulator ingests readings from the live edgePMU and simulates an over voltage event on three simulated nodes: node_21, node_22 and node_23. Each of these nodes is mapped to a real prosumer on the trial via the PBGM system policy interface, and once an over voltage event is detected by the Voltage Control service, the PBGM system is engaged to request flexibility from these prosumers through KIBERnet and a schedule is returned at such a time it is ready, enabling the Voltage Control to actuate and balance the over voltage occurrence. The figure below illustrates an expanded view of the interaction to include the simulated nodes and mapped prosumers (Figure 16).

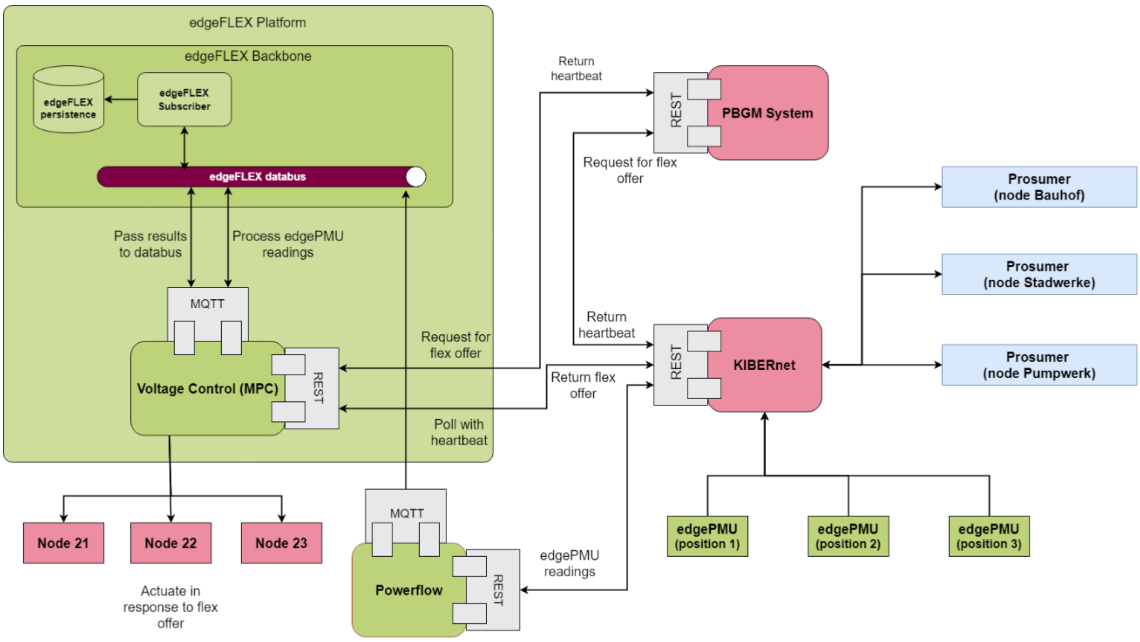


Figure 16 – Voltage Control trial interaction with prosumers

From the perspective of KIBERnet, as the market platform, the prosumers connected to the specific cable of the MV of SWW are divided into groups based on their node connection (Figure

17) in which each of the three nodes corresponds to one of the nodes mapped in the edgeFLEX platform.

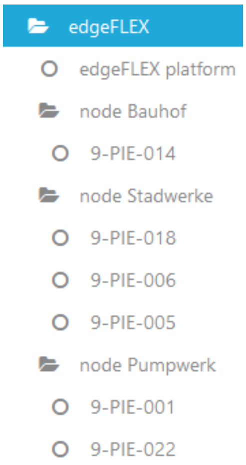


Figure 17 – Nodes of prosumers

In KIBERnet, the edgeFLEX platform is acting as an entity requesting the flexibility which other prosumers have offered. The platform forms one FlexOffer for each node requesting flexibility from another node. The scheduling algorithm scheduled the prosumers available at the time when the requests from the edgeFLEX platform were received, resulting in an assignment of prosumers to requests. Figure 18 shows the situation after scheduling, in which some of the prosumers have been matched and are "assigned" a schedule and in which other prosumers were not matched with any of the requests and their offers stay in the system (to be "re-offered"), in case their offer can be matched with any of subsequent requests.

Creation Time	Prosumer	Location	Status
2023-02-17 11:22	9-PIE-006	9-PIE-006	assigned
2023-02-17 11:21	edgeFLEX	node 3	re-offered
2023-02-17 11:21	edgeFLEX	node 2	assigned
2023-02-17 11:21	edgeFLEX	node 1	re-offered
2023-02-17 11:20	9-PIE-005	9-PIE-005	assigned
2023-02-17 11:15	9-PIE-022	9-PIE-022	re-offered
2023-02-17 11:15	9-PIE-014	9-PIE-014	re-offered
2023-02-17 11:15	9-PIE-018	9-PIE-018	re-offered

Figure 18 – Flexibility matching for each node

At the time of the demonstration, the prosumers on nodes 1 and 3 didn't offer flexibility suitable for request and were not scheduled. The request for node 2 activation was successfully scheduled with two prosumers. The scheduled prosumers received an operation schedule for activation which they tried to follow for the duration of activation. Figure 19 shows a graphical representation of one prosumer's schedule and FlexOffer that was the basis for this schedule. The offer shows that the prosumer offered negative flexibility for four intervals and was scheduled for the first two intervals of the four intervals. In the same sense, as prosumers, the edgeFLEX platform received back a schedule that contained combined energy amounts which were successfully scheduled for each node separately, so that a control action for controlling the DSO's assets could be performed.

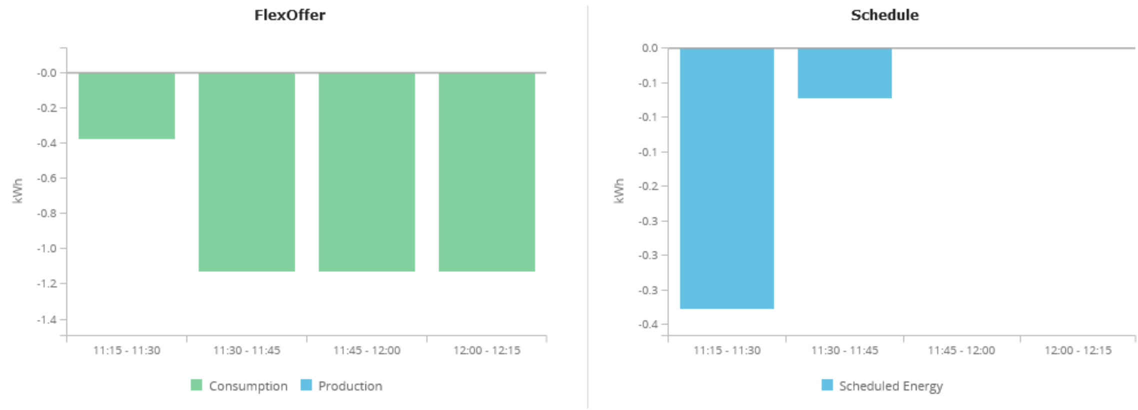


Figure 19 – Prosumer's offer with schedule

The outputs captured and visualised by the edgeFLEX Platform demonstrate the Voltage Control actuating and balancing the simulated over voltage event, as can be seen in the "Active Power" graph in Figure 20. Fine-grained detail regarding the flexibility is also included. The amount of time between engagements with the energy community, in addition to the boundary limits of the flexibility requests, are controlled via the PBGM system and can be updated by the user dynamically.

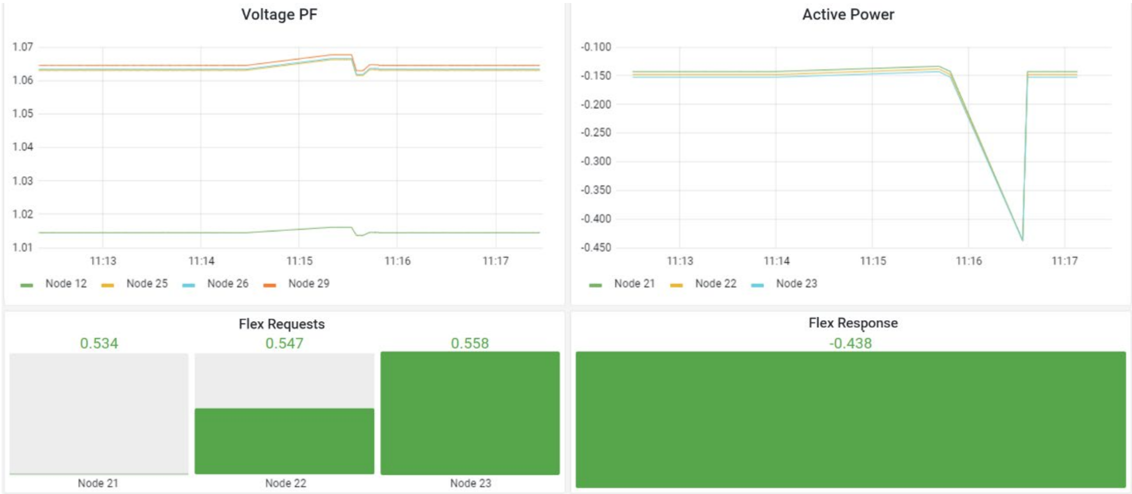


Figure 20 – Voltage Control over voltage actuation response

Figure 21 shows the power of a prosumer before and during the activation from which can be shown that the prosumer stopped producing energy with the start of the first interval of the schedule and restored production with the end of the second interval of the schedule.

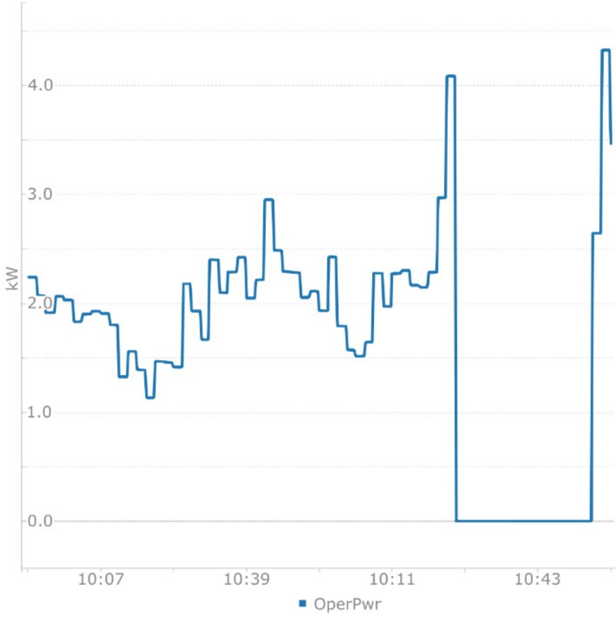


Figure 21 – Prosumer response on voltage control

A conclusion of the demonstration is that prosumers were scheduled according to their placement in node groups, based on one per node flexibility requests, by the edgeFLEX platform. Combined resulting schedules for each node were sent back from KIBERnet to the edgeFLEX platform to allow a control action for controlling the DSO's assets. The power adaptation of the prosumers was observed as a change in voltage by the edgePMUs installed on the cable on which the demonstration was performed.

6.2 Applying flexibility as a service for Congestion Management

Initially, we considered running tests with flexibility services for congestion management focusing on redispatch and more specifically Redispatch 2.0, however, such tests were not needed, as the results achieved in the voltage control tests can be used to generate offers of flexibility supporting services for congestion management and the implementation of Redispatch 2.0.

Redispatch refers to measures to counteract short-term grid congestions (deviation in the amount of electricity in the lines), which can cause outages if not resolved quickly. This is regulated under paragraph 13 of the German Energy Industrial Act (System responsibility of transmission system operators). As the DSO incurs responsibility for congestion issues to some extent from the TSO, congestion events must be addressed by the DSO. Flexibility of a system is measured by the degree to which electricity demand or generation can be adjusted, both anticipated and unanticipated, in response to changes on the grid [3]. This means that the system might respond to these changes with the aim of keeping the consumption-production scale level, i.e., consumption equals production. As curtailment is perceived as inefficient, the edgeFLEX platform generating flexibility offers can apply the modus operandi of the voltage control to allocate resources much more efficiently.

6.3 Testing the Energy Community acting as a VPP for provision of grid supporting services

The test of the EC, acting as a VPP, is simulated as the formal establishment of an EC is still not yet possible, as the relevant legislation has not yet been passed by the German government. The tests of the ability of the prototype EC to provide balancing services and bookkeeping

[3] Power system flexibility: A review. (2020)

functions can be performed in the live system. These tests are intended to investigate slow dynamics services.

The field trial in Wunsiedel uses the concept of the EC, acting as a VPP, to investigate changes in decentralised energy production and trading which are expected to be introduced the coming years in power grids. Instead of focusing only on energy production as VPPs currently do, the concept of an EC acting as a VPP includes energy consumption as well as production. The term EC refers to the active and collective participation of citizens in the energy supply chain in a defined regional community comprised of Prosumers, Consumers (both with energy storage capacities), Industry and local PV, Wind Power and Biomass plants as well as a peer-to-peer trading platform. An EC can thus be seen as a VPP but the opposite situation does not apply - a VPP cannot necessarily be seen as an EC. SWW Wunsiedel, as a regional driver of innovation, intends to further promote this approach to transformation in the energy market.

The tests performed show that while one asset can provide limited flexibility, multiple assets providing flexibility simultaneously offer the level of flexibility which a functioning VPP could provide. This demonstrates the ability of an EC, as the assets are owned by a defined community, to provide flexibility simultaneously from several assets thus fulfilling flexibility requests in the same manner as a VPP.

In this scenario the EC, which includes all the prosumers connected to the specific SWW MV cable used in the edgeFLEX field trial, are offering their flexibility in the same way as in the Voltage Control test. The difference here is that the activation request selects among every available prosumer in the EC, regardless of where they are connected to the cable.

For this demonstration, a FlexOffer was generated, requesting decreased production or increased consumption from the prosumers. Figure 22 visualises this request and shows that there was a request for flexibility for two 15-minute intervals. When this request was received, the KIBERnet scheduling algorithm scheduled existing offers to match the request. Figure 22 shows the situation after scheduling, in which some of the prosumers were matched and are "assigned" a schedule and other prosumers were not matched with any of the offers and their offers stay in the system ("re-offered") in case their offer will get matched with any of subsequent requests.

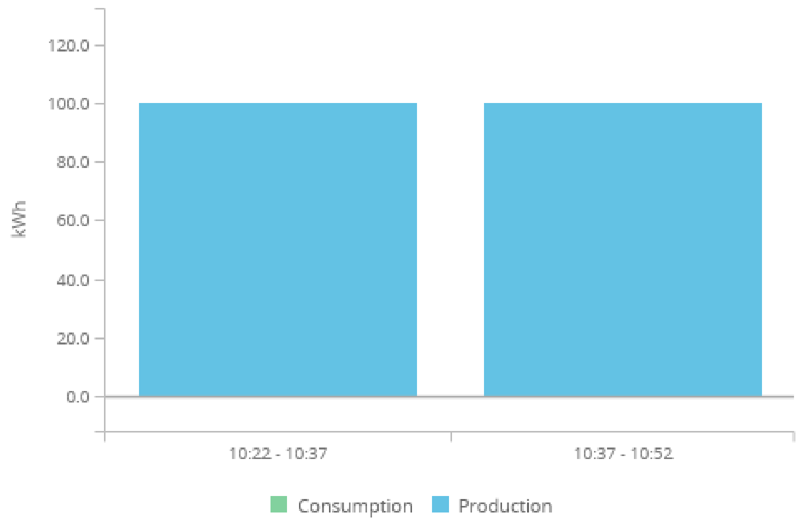
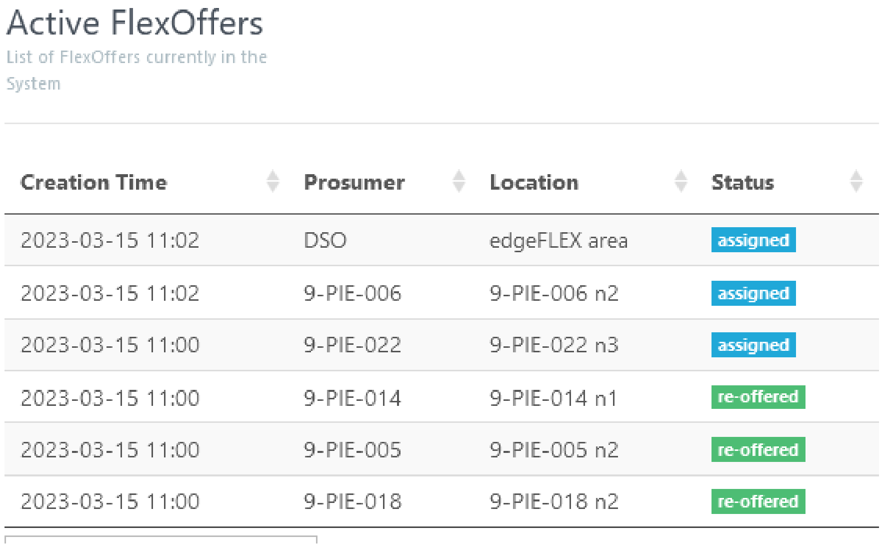


Figure 22 – Request for flexibility

The "DSO" offers in Figure 23 is the FlexOffer which is requesting flexibility. At the time of the demonstration, two offers were suitable for use to fulfil this request.



Active FlexOffers

List of FlexOffers currently in the System

Creation Time	Prosumer	Location	Status
2023-03-15 11:02	DSO	edgeFLEX area	assigned
2023-03-15 11:02	9-PIE-006	9-PIE-006 n2	assigned
2023-03-15 11:00	9-PIE-022	9-PIE-022 n3	assigned
2023-03-15 11:00	9-PIE-014	9-PIE-014 n1	re-offered
2023-03-15 11:00	9-PIE-005	9-PIE-005 n2	re-offered
2023-03-15 11:00	9-PIE-018	9-PIE-018 n2	re-offered

Figure 23 – Flexibility matching

When the prosumers have been assigned, they received an operation schedule for activation which they try to follow for the duration of activation. Figure 24 shows a graphical representation of one prosumer's schedule and FlexOffer which was the basis for this schedule. The offer shows that the prosumer offered negative flexibility for four intervals and got scheduled for the second and third interval. Figure 25 shows the power of a prosumer before and during the activation. It can be seen that the prosumer stopped producing energy at the start of the second interval of the schedule and restored production at the end of the third interval of the schedule.

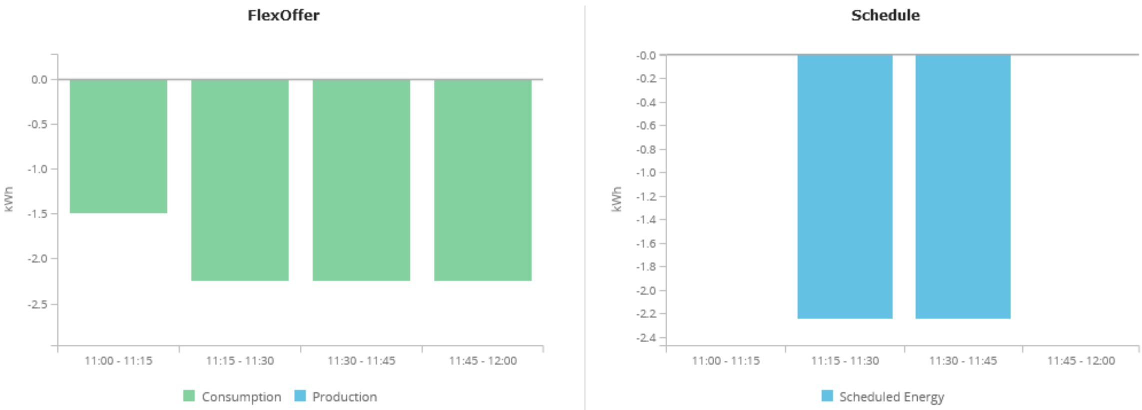


Figure 24 – Prosumer's offer with schedule

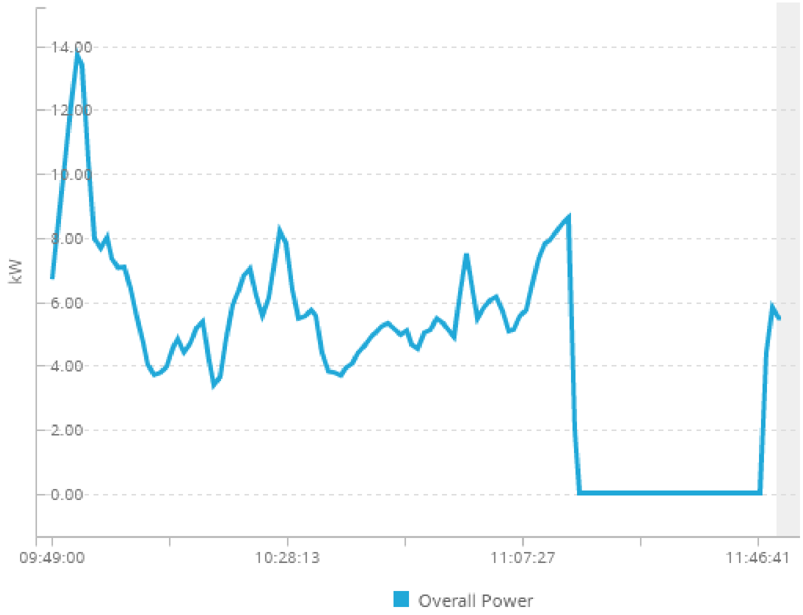


Figure 25 – Prosumer’s power during activation

A conclusion of the demonstration is that prosumers which had flexibility available to match the request were scheduled for activation and that they adapted their production or consumption according to the schedules distributed. These schedules were a result of scheduling with a received FlexOffer requesting flexibility, meaning that the prosumers were acting as a VPP.

6.4 Conclusion of Chapter 6

The Voltage Control test infrastructure is a demonstration of how intelligent ancillary services, combined with the engagement of the energy community, can be utilized to solve balancing issues locally on the grid. This trial showcases the capabilities of the Voltage Control service, in combination with the edgeFLEX Platform, PBGM system, and the KIBERnet market platform to request flexibility from customers to mitigate overvoltage events in an automated and dynamic fashion. Overall, this infrastructure presents an approach to voltage control which can minimize the amount of power injected or absorbed by the assets required to solve the voltage issue, while ensuring customers get requests for the minimum amount of flexibility needed to support the grid, with the remaining flexibility available to be used for other purposes.

The results achieved in the voltage control test were also used here to generate flexibility offers to support services for congestion management.

The field trial of the Energy Community acting as a Virtual Power Plant investigated how to introduce changes in decentralised energy production and trading which are expected to be introduced in the coming years in power grids. The test showed that the EC acting as a VPP can provide flexibility and fulfilling flexibility requests in the same manner as a VPP. Furthermore, the test showed the ability of an EC to provide balancing services, specifically slow dynamics balancing services.

7. Exploitation and learnings

SWW is aiming to fully exploit the results of the field trial as well as the lessons learned during the edgeFLEX project, as it is crucial that other municipal service providers or comparable market operators profit from them. The wider implementation is results is essential to achieve a systematic and holistic change in the German national grid, and not only in a local grid. The following and last chapter of this document therefore tackles the topic of exploitation, how the most important and novel results can be exploited, and it describes the learnings SWW could extract from the results. This chapter is intended to serve as an empowerment and guideline for interested stakeholders.

7.1 Exploitation

The approach described in Chapter 5, is intended to act as a blueprint for other grid operators wishing to incrementally evolve towards utilising flexibility, and thus ultimately improving the grid operation.

The incremental evolution in SWW involved taking measures to induce the integration of the VPP 2.0 in its trial. In contrast to the traditional VPP approach, which relies on large assets, the edgeFLEX VPP2.0 concept allows smaller assets to be included and as a result increases citizen participation and creates higher acceptance of RES. VPP2.0 offers a much more transparent view of events within the grid, while enabling addressing various supply issues which need fast and slow reactions and includes the provision of services from smaller prosumers. This VPP2.0 concept was realised in the SWW trial site including setting up an EC as a prototype - the real integration is not yet allowed in Germany as the relevant legislation has not yet been passed.

Due to the lack of a regulatory framework in Germany enabling a functional EC to formally exist, SWW has resolved to become a full BRP for the area of Wunsiedel by 2025. As part of the process to realise this goal, the edgeFLEX services and solution envisioned by the project are planned to be implemented, in order to use local flexibility to increase the operational efficiency of the power network. Moreover, SWW assumes additional roles as described in chapter 5 and this is referred to as the “all-in” approach. The responsibility of a BRP involve being an active player on the energy exchange markets. In the SWW case, this involves using the local EC and VPPs for physical balancing purposes. This approach aims to evolve the SWW responsibility towards enhanced grid management capabilities.

The VPP 2.0 and the “all-in” approaches work in synergy and complement each other.

7.2 Key exploitable results

The novelty of the edgePMUs and edgeFLEX Platform and services is that the Energy management system is connected to a data processing platform, while benefiting from advanced monitoring hardware. The added value of this approach is that flexibility offers can be generated. This not only leads to enhanced grid operations but also contributes to local community system resilience, as local prosumers and consumers enhance exchanges among themselves. Furthermore, it results in improved transparency of the grid status due to the capabilities of the edgePMU and edgeFLEX services. SWW is planning to use this technology on other lines in their grid for managing its power network. These implementations have been integrated into the SWW published plan for "The Wunsiedel Way of Energy 4.0" and the technology is demonstrated already to visitors of the SWW Energy Park.

Regarding flexibility, the novelty of the field trial is that multiple prosumers and assets were integrated and equipped with EMSs and therefore they could make a high level of flexibility available to the grid. The prosumers are integrated into the energy grid and enabled to make full use of their electricity, while saving costs. On the DSO side, the grid is more stable and easier to monitor. The flexibility allows the DSO to save costs and reduce the electricity to be produced to be sure that the DSO can cover the consumers' minimum needs. All experience gained is described in the earlier published deliverables of edgeFLEX and through demonstrations to on-site visitors travelling to the SWW facilities in Wunsiedel, Germany. For 2023, the target number of visitors planned is 25 official visitor groups with 25 visitor members per group. This number does not include project groups as they are considered separately.

Within the edgeFLEX project, FlexOffers have been generated for the first time and voltage control is now available, which allows the voltage to be stabilized in ways that were not possible previously. Voltage control via flexibility offers enhances grid operations and lowers power losses within the grid, while providing a safe, secure and continuous power supply to the customers.

With regards to customer integration, edgeFLEX offers the novelty that small system owners can participate in the energy supply chain, which leads to a high rate of user engagement. This development offers a path towards both higher level of user acceptance and faster user acceptance of new provisioning schemes while the system operators gain confidence because of the implemented field trials.

Each of the 25 integrated energy management systems, installed in homes and companies, provide enhanced grid monitoring abilities. This novelty enables an exemplary display of energy consumption in private households and companies. It not only enables the comparison of the loads and demands, but also the identification of habits and trends. Different customers can offer different opportunities for load shifting. Further, both types of stakeholders, both households and companies, are getting accustomed to the principle of flexibility trading and provision. Potential threats or no-goes have been identified. Also here, a high rate of user engagement enables a higher level of, and quicker, acceptance for new provisioning schemes, while the system operators gain confidence as a result of the implemented field trials.

The electric storage systems of the 50 integrated customers are used as a buffer for the business processes of SWW and are critical to flexibility availability. The value of this novelty is that it allows the provision of flexibility, not only in the form of real-time increases or decreases of load, but also as long-term provision schemes. Buffers make flexibility provision even more flexible and available when needed. This is especially important with regards to business processes, as they are much more sensitive and dependant on a stable grid than households.

Moreover, a presentation on the edgeFLEX stakeholder interaction has been made in the BRIDGE Stakeholder Interaction working group and a paper on edgeFLEX stakeholder interaction has been prepared for publication in the BRIDGE handbook publication.

The grid reinforcement strategy of SWW has been developed specifically to allow high-penetration rates of RES while avoiding grid disturbances. This strategy is validated by the trial results in edgeFLEX and will allow SWW to transfer their strategy to other grid operators who also operate small scale grids. The outcomes of the edgeFLEX trial can be distributed to and shared with a large group of interested people, which will enlarge the impact even more. The project results encourage SWW to continue working to implement their ideas and goals.

7.3 Result learnings

The key exploitable results have given insights on how the edgeFLEX services can benefit system operators:

- **Grid:** The grid status is more transparent and has been improved by the edgePMU and edgeFLEX services. These services provide more accurate and timely information on the grid conditions, which helps SWW to make better decisions about grid operations. In addition to that, the trial results also show that the investment in grid improvements has been successful. The consequence in general is a higher grid performance.
- **Flexibility trading:** Storage systems as buffers play a critical role in flexibility-based business processes. Without them, flexibility only relies on suitable power plants which can produce more, or less, energy on demand. Overall, storage systems are indispensable in efforts to meeting customer or grid requirements in a sensible way.
- **Energy Community:** The potential to increase grid flexibility and improve efficiency with an Energy Community has been demonstrated. These communities can bring together consumers who want to become active participants in managing the supply of, and

demand for, energy. The willingness among consumers is high. In doing so, they can help to optimize the use of energy, and improve the reliability and stability of the grid. The Benefits of the Energy Community to the grid operator can be described as followed:

- Improved transparency of the grid status,
- Use of storage buffers for business processes,
- Strategy concepts for strengthening the grid are implemented,
- The EC generates a high potential for flexibility services,
- A higher penetration rate of RES is enabled, and
- Better energy and assets management is enabled.

7.4 Conclusions of Chapter 7

The exploitation plan shows that the results of the SWW trial are of high value for grid operators wishing to increase the proportion of renewable energy sources in their grids as well as to use flexibility. It serves as a blueprint, based on the VPP2.0 approach, which, in contrast to the VPP1.0 approach, is based on integrating a large number of small assets, and thus, allowing private people with suitable assets to join the VPP. This brings benefits to the grid such as higher transparency as well as increased efficiency. When the necessary legislative and regulatory issues have been addressed by the National government in Germany, the following results could be widely deployed:

SWW was able to produce exploitable results showing novelties in the areas of:

- EdgePMUs and services/platform,
- Flexibility,
- Voltage control,
- Customer integration,
- Integrated systems in homes and companies,
- Customer energy storage, and
- Grid reinforcement strategies.

Furthermore, SWW identified learnings from the results regarding:

- Grid (e.g., transparency),
- Flexi trading (e.g., role of storages as buffers),
- Energy Community (provision of flexibility and efficiency), and
- Benefits of the Energy Community.

8. Conclusion

The trial deployed concepts developed in edgeFLEX, in some cases building on the results of earlier projects, in a live operating grid in Wunsiedel, Germany. The services deployed offer slow and fast dynamics, enabling energy supply and stability, while different locations and stakeholders were included in the trial, in order to form an Energy Community. Within the trial the concepts of voltage control operating in conditions of over voltage, and that of an EC operating as a VPP were tested. Both sets of tests also included the generation of flexibility offers to counteract changes happening in the grid. The goal of collecting and evaluating the data of this field trial was to achieve an unobstructed data transfer between local measurements, the installed EMS and the edgeFLEX platform. This relates to the main goal of the edgeFLEX project, which aims to accelerate the integration of distribution solutions and to establish a market for flexibility trading.

The impact of the Key Exploitable Results (KERs) of this project can be divided into different subtopics. The edgePMUs and the edgeFLEX solution enable flexibility offers can be generated, which leads to enhanced grid operations and contributes to the local community power system resilience as both local consumers and prosumers exchange electricity among themselves. Through the integration of multiple prosumers and assets, a high level of flexibility can be made available to the system operator. While prosumers can therefore make full use of their electricity and save costs, the DSO gains the advantages of a more stable and easier to monitor grid. The edgeFLEX voltage control function allows the voltage to be stabilized, reduces losses within the grid and provides a continuous and safe power supply. By including prosumers in the energy supply chain, the rate of user engagement is increased and the basis for a quicker and higher rate of acceptance for new provisioning schemes is achieved. The integrated systems in homes and companies display the energy consumption from these sectors and give the option of engaging them in flexibility trading. The integrated customers electric storage systems on the other hand, buffer the business processes connected to flexibility and make them available for long term planning. The grid reinforcement strategy of SWW has been validated through the edgeFLEX field trial and this positive experience can be transferred to other grid operators.

Learnings were identified in relation to the grid, flexibility trading and energy communities. The grid benefits from improved transparency of the grid status due to the edgePMU and the edgeFLEX services. The newly developed edgePMUs requires a high-rate of raw data transmission between acquisition device and edge cloud using wireless connectivity, while the cloud-based, virtualised software can also be used to calculate other grid metrics. The SWW strategy of investing in grid improvements is further validated by the trial results. The role of flexi-storage buffers is critical to flexibility-based business processes in flexibility trading. The Energy Communities' potential to increase grid flexibility is demonstrated and there is a high willingness among consumers to join and become an active part of the energy supply chain through participation in an Energy Community. This engagement by the users was essential to the success of the project and was supported by activities such as design thinking workshops and the publication of newspaper articles, throughout the duration of the edgeFLEX project.

The voltage control tests showed that over voltage events can be eliminated using flexibility for fast dynamic services. Furthermore, the edgeFLEX platform generating flexibility offers do not just apply the modus operandi of the voltage control to allocate resources much more efficiently, but they also use them voltage control to avoid congestion issues. Using an EC as a VPP proved it is feasible to provide flexibility and balancing services for slow dynamic services while enabling multiple stakeholders to resolve grid events.

9. List of Tables

10. List of Figures

11. References

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12. List of Abbreviations

AS	Ancillary Service(s)
BGM	Balance Group Manager
BRP	Balance Responsible Party
CEF	"Connecting Europe" Facility
CHP	Combined Heat and Power
DRES	Distributed Renewable Energy Source(s)
DSO	Distribution System Operator
EC	Energy Community
EMS	Energy Management System
FEMS	Factory Energy Management System
FlexOffer	Flexibility Offer(s)
HEMS	Home Energy Management System
HV	High Voltage
MPC	Model Predictive Control
MV	Medium Voltage
PBGM	Policy Based Grid Management System
PMU	Phasor Measurement Unit
RES	Renewable Energy Source
RoCoF	Rate of Change of Frequency
TSO	Transmission System Operator
VPP	Virtual Power Plant