MARKET ENABLING INTERFACE TO UNLOCK FLEXIBILITY SOLUTIONS FOR COST-EFFECTIVE MANAGEMENT OF SMARTER DISTRIBUTION GRIDS

Extract from deliverable 10.5: Key exploitable results

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1 EUniversal achievements and results

In this chapter, we will start showcasing the different tools and methodologies that have been developed, tested, and implemented during the project. In section 2.1, we start with an overview of the key exploitable results (KER). The interested reader can, however, look in the appendix where each partner filled in a template with a more elaborated explanation of its tools. In section 2.2, we summarize the demonstrator results. Finally, in section 2.3, we analyse the different KERs and demonstrator results, and discuss strengths, weaknesses, opportunities, and threats that we endured and discovered throughout the project. This SWOT analysis will give first insights in the key lessons learned which will be discussed in detail in chapter 3.

1.1 Key Exploitable Results

EUniversal project results include 19 Key Exploitable Results (KERs) of all the different partners. Figure 1-1 presents a summary of all KERs grouped per project pillars. In this chapter, we present one-page descriptions of every KER. A detailed description of every KER, obtained through interviews with the involved partners, can be found in **Error! Reference source not found.**. In Figure 1-2 we describe how the KERs in the DSO toolbox are used in the different demonstrators. In what follows, we describe each Key Exploitable result in more detail. Each description of the KERs contains a statement about the problem, the solution, the Unique Selling Points (USP), value and expected impact.

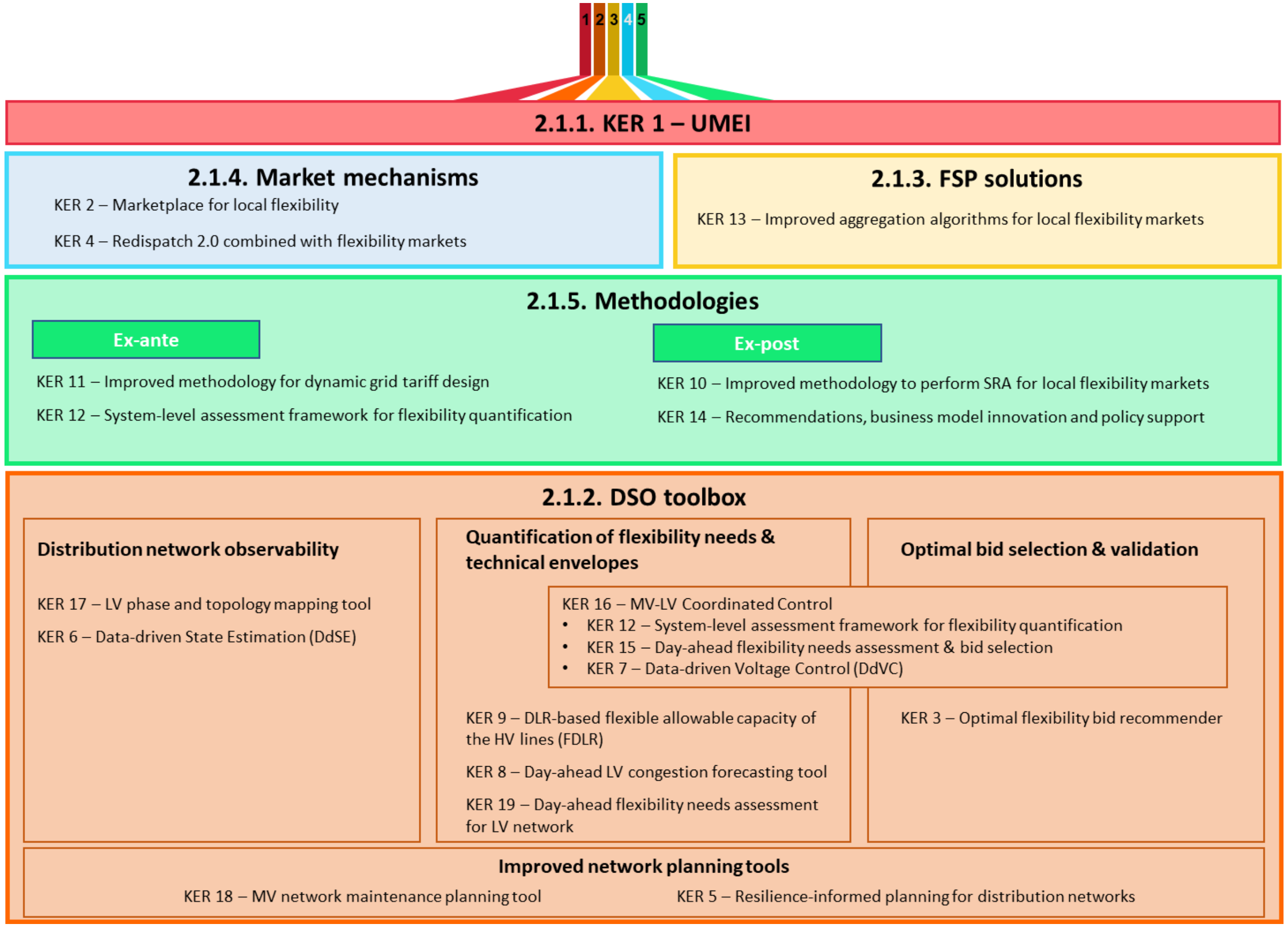


Figure 1-1: Key Exploitable Results

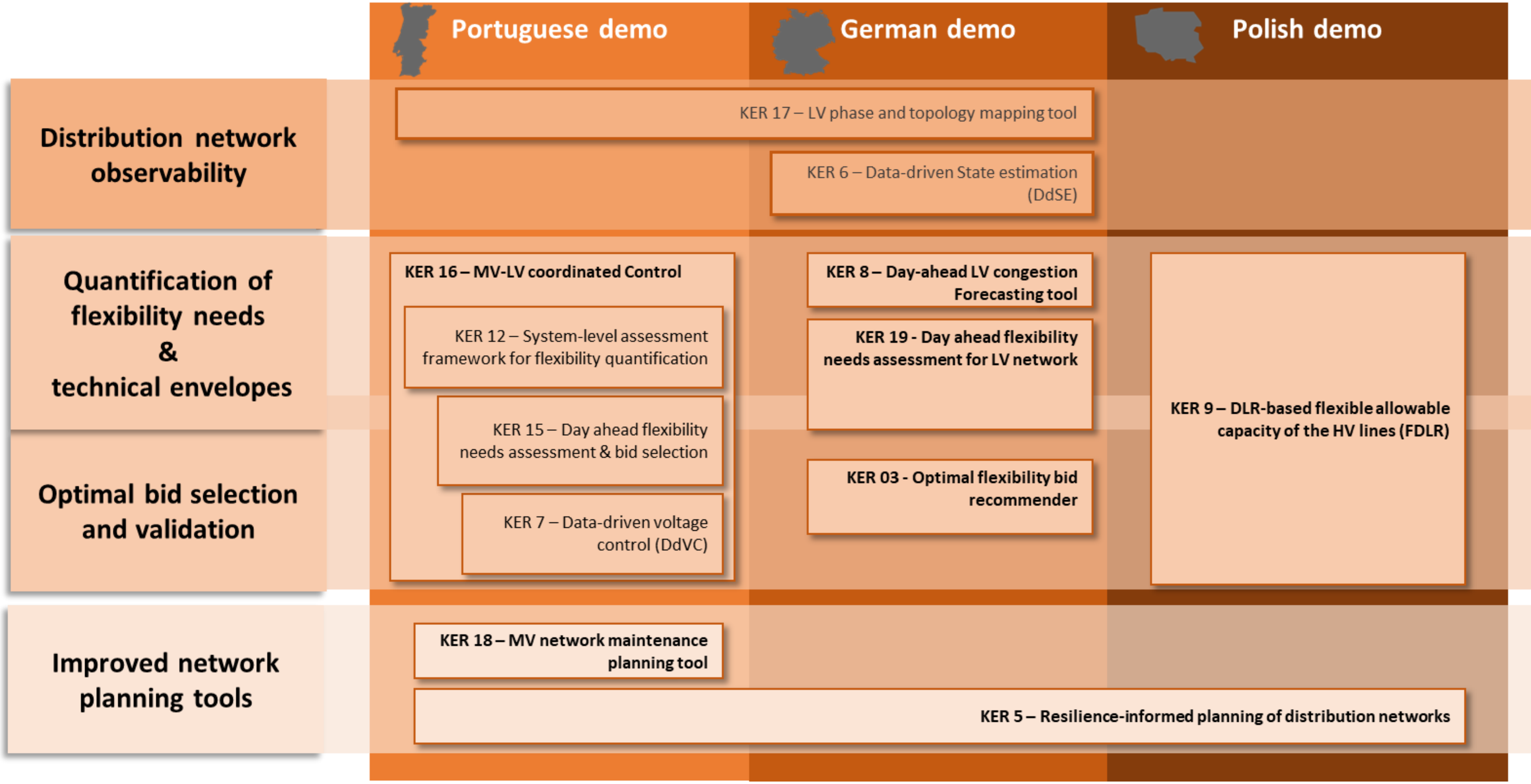


Figure 1-2: KERs in the different demonstrators- DSO Toolbox

KER 1

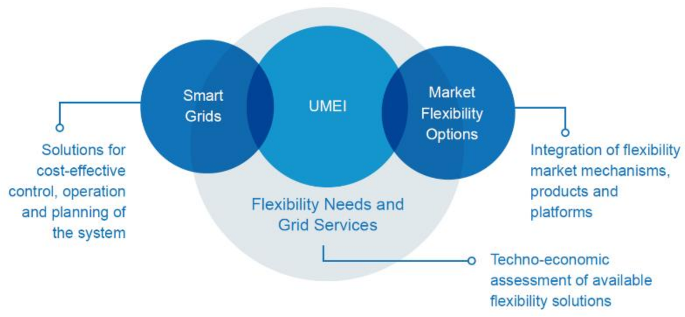
Pillar 1 UMEI: Universal Market Enabling Interface

Partners: E-REDES, NODES, N-SIDE, Centrica

Problem

Given the increased need for flexibility, pilots and test projects are being set up to test local flexibility markets. The current market immaturity and regulatory unclarities result in many different solutions and a lot of diversity in market implementations. This diversity limits the adaptability and the usability of different solutions, and implies that system operators that aim to set up local flexibility markets would need to comply with the different market platform specifications. Each time a DSO wants to start setting up a new flexibility market with another market operator, it would need to start from scratch to integrate all systems with its internal environment. This creates a lock-in in one specific market platform and increases barriers for DSOs to benefit from multiple market platforms. In addition, other stakeholder costs increase since the would have to implement different communication/interaction processes for each individual market platform by adding an additional layer of data management to adapt communication to the specific requirements of each market platform.

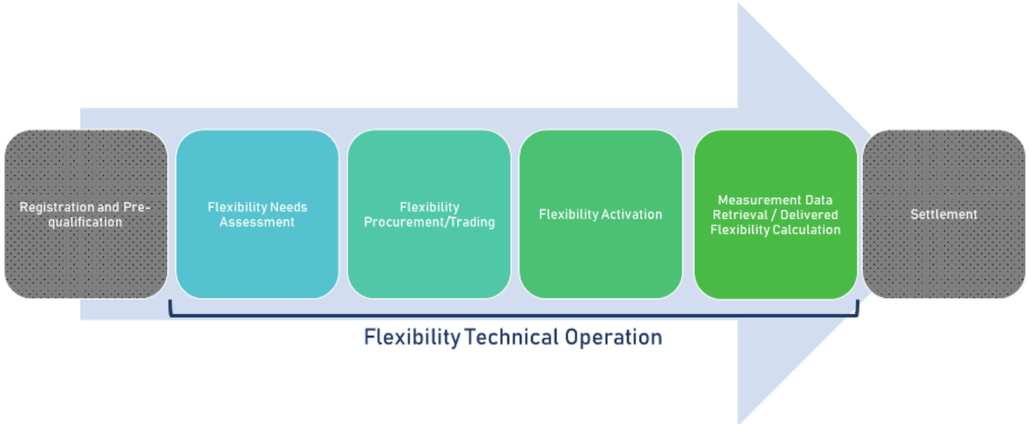
Due to the current market immaturity and the lack of standardization, there was no other similar decentralized solution. Most stakeholders build further upon their current systems in the best feasible way. The UMEI solves this by creating an interface that helps bringing different stakeholders together and demonstrates that it is possible to ensure direct interactions between DSOs and other market players. More specifically, the UMEI is a standardized interface that allows all stakeholders to interact with each other. It is a conceptual architecture design and implementation of a standard, agnostic, adaptable, and modular combination of different APIs to link DSOs and market parties with flexibility market platforms, in coordination with other flexibility users. This approach allows distributed communication without the need for a central hub.



Solution

It therefore creates a common way for market actors to interact with the flexibility markets and amongst themselves, without the need of mediator components, such as data hubs or platforms, to procure system services for the distribution grid operation. This new implementation allows for quick uptake. The UMEI consists of publicly available APIs, allowing any stakeholder to adopt them or to develop new APIs concerning new services while complying with the UMEI interface specification. An application programming interface (API) is a way for two or more computer programs to communicate with each other. It is a type of software interface, offering a service to other pieces of software. APIs connect solutions and services without the need to know how these were implemented by each part. In **Error! Reference source not found.** in the introduction, we already depicted how the UMEI's setup connects different stakeholders by linking the different pillars. The figure above describes the different UMEI functionalities that have been developed in the EUniversal project: flexibility zones, portfolio management, baseline calculation, market access, order management, market trades and meter readings.

The market process supported by the UMEI are visualized in the figure below. Apart from the registration, prequalification and settlement, all processes are covered.



USP

UMEI is adaptable and is not a rigid standard that obliges every market platform to take over the specifications of the UMEI. The demonstrated capability of UMEI of working with multiple market platforms allows stakeholders to offer and procure flexibility from multiple platforms. DSOs are not locked to one specific flexibility provider and/or market platform. Switching between platforms does not require new developments, giving DSOs more freedom to choose. In addition, UMEI is open-source and publicly available, both through the project website and Github.

Value and impact	Customer
Open end-to-end communication interface	DSO, FSP
Available set of components for interfacing with market actors	FMO
New incentive and revenue opportunities due to easier flexibility market access.	End Consumers
Support to innovative business models due to its decentralized nature.	Service Companies
Ensure a cost-effective and fast energy transition	Society
Customization possible towards different needs	Energy system
In support of market framework for flexibility, in which all consumer groups can participate	EU/national policy

Pillar 4 Flexibility Market

Partners: NODES and N-SIDE

KER 2

Problem

Load patterns have changed due to digitalization, RES and electrification. Grid problems became more frequent and spatially more granular. Market-based flexibility enables DSOs to use local and regional small-scale flexibility from the LV and MV grid to solve grid problems and to prevent the propagation of the congestion into different grid levels. However, FSPs still face numerous barriers to offer their flexibility. European standards and network codes are required to overcome the existing barriers (the lack of smart meters, minimum flexibility bid size, identification, and remuneration) and to create guidelines for the provision of market-based flexibility.

In EUniversal two market platforms have been tested, i.e. NODES and N-side. The market platform of NODES allows system operators to pick the optimal solution for their specific grid problem. NODES market platform performs the matching considering volume, location and price, while creating a level playing field for all types of assets and covering all functional requirements of the three phases: Registration and prequalification, Trading and Validation and Settlement. The registration and prequalification are done with minimum data requirements and according to GDPR standards. N-SIDE's market platform uses an auction-based mechanism to select optimal bids to solve issues in the DSO's grid. An advanced market clearing process, based on state-of-the-art optimization models and algorithms, concentrates the liquidity of the market with a closed-gate mechanism, before clearing it by maximizing the social welfare while respecting the asset and network constraints. Both platforms have their individual strengths and are described in the annex and in the introduction in chapter 1.

Impact

The market platforms help to optimize the use of the available grid capacity due to the effective use of available flexibility assets. This can lead to:

- Prevention of unnecessary curtailment of renewables;
- Reduction of grid expansion costs;
- Reduction of the electricity bill of end-users
- Reduction of the reaction time in case of congestions;
- Respecting local and regional grid limitations
- Bridging bottlenecks in the energy supply chain.

	Value	Customer
NODES	Distributed flexibility of any size to SOs for grid management.	DSOs, TSOs
NODES	Asset owners can monetize flexibility by selling energy in the flexibility market to help SOs manage grid constraints.	FSPs, Aggregators, BRPs
N-SIDE	Market clearing through a welfare maximizing algorithm respecting network constraints.	DSOs, TSOs, FSPs, Aggregators
N-SIDE	Dynamic flexibility areas to handle network constraints modularly	DSOs, TSOs, FSPs, Aggregators

Pillar 2 Optimal bid recommender (ORB)

Partners: N-SIDE

Problem

Minimizing the cost of the flexibility that will be provided to the system is one of the main challenges in this topic. A market clearing process consists of a grid-aware optimization problem that finds the best combination of flexibility demand and offer orders (i.e. the combination that solves all congestions at the lowest cost). When this is done at Market platform level, the drawback is that the System Operator (SO) must share data about his grid with an external organization (market platform) which can be a sensitive topic. Furthermore, it is also plausible that there are multiple flexibility platforms operated in parallel, increasing the market liquidity. Yet, the drawback is that if each platform optimizes the flexibility on its own, without considering flexibility offered on other platforms, it is impossible to reach a global optimum. However, to perform a global optimization considering sell bids from multiple market platforms could be more complex.

Solution

To tackle these challenges, N-SIDE created the optimal bid recommender (OBR). This tool is a clearing engine that can be installed directly on the SO's servers and that can be used as a tool to help select the best possible selection set of flexibility bids. Instead of having the flexibility market platforms (FMO) performing the clearing, it is the DSO that runs an optimization algorithm (within the OBR). The OBR tool can use both the data fetched from multiple market platforms that operate in parallel, and the DSO grid-data. In this configuration the DSO can keep full control of both their data and actions. This solution can profit from serve different market platforms. Currently, it is a market-based solution, but it could be adapted to redispatch solutions with different types of contracting (smart energy contracts...). This approach would combine both the security of a direct control solution and a market solution.

USP

The OBR ensures effective use of available resources even if shared across multiple market platforms while keeping full control of the data. In the German demo the OBR is part of Mitnetz' cascading approach to their toolchain. In this approach the DSO has direct control, showing the flexibility of the tool.

Value	Customer
Data privacy: The OBR can run on the SO servers, meaning there is no need to share data (such as grid topology) with external actors. The actual contracting and FSP management is done directly by the SO.	DSO/TSO
Optimization of flexibility offered through multiple platforms	
Ensuring grid stability: the SO can input its most up to date grid topology and forecast, ensuring that the flexibility offered will solve congestions.	

KER 4

Pillar 2 Flexibility for Redispatch 2.0

Partners: MITNETZ, E.ON, CENTRICA, NODES

Problem

Since more congestions are predicted due to the increased share of renewable energy sources with intermittent production, there is a need for alternatives to manage congestion. Therefore, a more effective use of local available flexibility from the LV grid is needed. Specifically, in the German demonstrator, the approach of combining market-based flexibility procurement with Redispatch 2.0 is a promising approach to implement an effective mitigation of congestions across all grid levels. However, the regulatory framework for flexibility markets is under development and insights from the demo could be used to support its adjustments.

Solution

This KER tests the feasibility of combining the cost-based approach (Redispatch 2.0) with the market-based approach. Several tools were developed and interconnected to correctly assess the state of the grid and the flexibility needed in terms of quantity, time and location in the LV grid. Mitnetz, as DSO, will then evaluate the existing offers (submitted by Centrica as FSP) on the market in addition to the assets available according to Redispatch 2.0 and select the offer that most effectively solves the grid constraint at the best price. Note that this tool is different from KER 12 (System-level assessment framework for flexibility quantification) because the approach of KER 12 solves all voltage levels in a single mathematical problem. This would not work everywhere since different system operators can have different resources at different levels. Therefore, this KER opted for a cascading method, iterating from the LV to the HV, and back.

USP

Flexibility markets are a complementary tool to cost-based redispatch for grid constraints. They use existing and available assets to reduce or prevent unnecessary grid investments.

Flexibility can also be an interim solution while the grid can be reinforced when there is a repeated issue in the same location. Regulation incentivises CAPEX, new investment in lines, rather than OPEX solutions like flexibility.

Value	Customer
Access to added available flexibility	DSOs, FSPs
Effective complementary solution to Redispatch 2.0	DSOs, FSPs
Incentive for adaptive behaviour of customer	FSPs, utilities, residentials
New business model creation, enabling more parties to offer flexibility	FSPs, aggregators, utilities
Transparency & neutrality for flexibility procurement	DSOs, FSPs
Visibility and accessibility of distributed assets	DSOs

KER 5

Pillar 2 Resilience tool

Partners: UCY, INESC TEC

Problem

As weather patterns grow more extreme and frequent, the impact they have, and the resulting damages they cause on power systems increases. E.g., in 2018, Hurricane Leslie caused more than 15 thousand homes in Portugal to lose power and roads across the country were severely damaged, which increased the response time to repair the power supply losses. The existing methodologies used to plan distribution networks focus primarily upon reliability of the networks over extended periods of time. This approach focuses on the routinely planned maintenance necessary to keep the network operating for decades at a time. It does not, however, consider the impact of individual events that have the potential to cripple the network in a matter of hours or days. As a result, it is imperative that system resilience becomes an integral component of planning methodologies to ensure that ST impacts are accounted for with as much importance as LT degradation is currently.

Solution

A framework and a methodology were developed in parallel within this KER to address this existing limitation. The former is an optimal investment planning framework for MV distribution grids that has two separate tools: (1) a hazard scenario generator and (2) an optimizer. The hazard scenario generator was developed from network fragility curves and accounts for the vulnerability of the individual network assets to natural hazards. These scenarios are then compiled, along with the potential investment options, within the optimizer to develop optimal investment portfolios that balance system reliability with resilience. The latter is a reliability evaluation methodology that determines load loss from a state evaluation process. This is accomplished via a time-dependent understanding of the existing flexibility and its energy limitations within the system. The method uses the assets proposed by the planning tool (the resilience planning framework) to evaluate the system reliability under anticipated regular events.

USP

By providing DSOs with the ability to select their preferred level of risk (risk averse, risk neutral, or partial-risk), this tool enables them to adequately plan their investment strategy for network reinforcement and flexibility enhancement assets. For example, in the Portuguese Demo, for an investment of €6 million, the tool improves the system performance against windstorms with expected energy not served by 36.79% and the conditional value-at-risk of energy not served by 28.29% from the base case (without any asset upgrade) for the scenarios considered. Moreover, with the same asset options, the popular reliability indices such as SAIDI and SAIFI improved by 27.14% and 25.49%, respectively.

Value	Customer
Risk-based resilient investment planning: helps DSOs to stick within the allocated budget	DSOs, Power system planners, NRAs
Improved distribution network resilience	All customers, DSOs
System performance: using the best assets based on risk-driven resilience metrics	DSOs, NRAs
Decrease natural hazard events impact on power systems	Society, policy makers

KER 6

Pillar 2 **Data Driven State Estimator** **Partners: INESC TEC**

Problem

DSOs currently have limited monitoring capabilities for LV networks. Combining this issue with the increase in DERs and EVs, DSOs face a number of growing challenges such as voltage/congestion issues and quantification of flexibility needs. The greatest challenge, however, is the lack of visibility of these problems as a result of the limited monitoring capacity. Without knowledge of the problems in real-time, DSOs are unable to adequately address them in a timely fashion. Unfortunately, the installation of real-time communication meters across an entire system is not economically viable in a short-term setting.

By using the existing smart meters within a LV network, the Data-driven State Estimator (DdSE) provides real-time estimation of voltage and active power across the entire network, even without full network observability. It accomplishes this by combining historical data and real-time measurements provided by the existing smart meters within the network. This allows the DdSE to create estimated consumption profiles for each metering point without the need of topological or electrical network information, while quantifying the uncertainty of each estimate. The DdSE goes even further by integrating weather measurements and forecasts into the meter profile estimates. This provides real-time results with improved accuracy for LV networks with high DER integration.

Solution

USP

The DdSE leverages historical data from existing smart meters, real-time measurements, weather forecasts, and other measurements to provide real-time state estimation in LV grids. Compared to existing approaches, the DdSE provides more accurate estimates without the need of full network observability, topology, or electrical characteristics.

The KER goes even further by providing conditional uncertainty for each estimate in the form of quantiles. These enable the operator to have improved awareness of the significance of the information alongside potential network issues identified through probabilistic alarms.

Additionally, the integration of weather data and forecasts further improves the estimate accuracy for LV systems that have a high integration of renewable resources, like PV panels.

Value	Customer
Improved knowledge of voltage violation occurrences	DSOs
Enables flexibility use to solve voltage problems	DSOs
Enables flexibility exchange without compromising volage limits	DSOs
Enhance overall reliability and efficiency of LV	Society
Real-time estimations w/o substituting equipment that do not communicate in real time	Society, DSO, consumer

KER 7

Pillar 2 Data Driven Voltage Control

Partners: INESC TEC

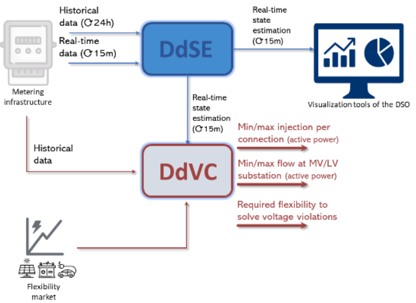
Problem

Voltage control at LV grid is one of the challenges to be addressed to ensure quality of power supply, when dealing with large scale integration of distribution energy source and new loads as electric vehicles and heat pumps. This would enhance the overall quality of service for consumers and minimize curtailment of distributed generation due to over voltages. However, accurate forecast and identification of voltage issues is difficult these days as conventional flexibility management tools require a complete topological and electrical model of the grid, which is typically incorrect or inexistent in LV systems.

Solution

Considering the limitation of existing methods, the DdVC (Data-driven Voltage Control), based exclusively on the historical data of the installed smart meters, can quantify flexibility needs, flexibility ranges and select optimal bid offers when applicable. The DdVC provides exploitable results for effective voltage control in LV networks. It calculates sensitivity factors, offers preventive and real-time capabilities, determines flexibility perimeters and ranges, selects flexibility bid offers, and conducts system state analysis. These results enable accurate voltage control, proactive violation detection, optimized flexibility utilization, and informed decision-making for improved LV network performance.

USP



The selling point of the DdVC is its data-driven approach tailored specifically for LV networks. It stands out by utilizing the existing smart metering and measuring infrastructure, eliminating the need for additional measurement equipment. This approach ensures cost-effectiveness and operational efficiency by leveraging the available infrastructure without requiring additional installations. Furthermore, the DdVC implements a privacy-preserving strategy, ensuring the confidentiality and protection of sensitive data collected from smart meters.

Value	Customer
Enables the use of flexibility to solve voltage issues	DSOs
Enables flexibility exchanges without compromising voltage limits.	DSOs
Market clearing tool: select the most cost-efficient solution to solve violations	DSOs
Enhance service for customers	Customers
Optimize utilization of RES by controlling voltage issues.	Society
Minimize operational network costs	DSOs

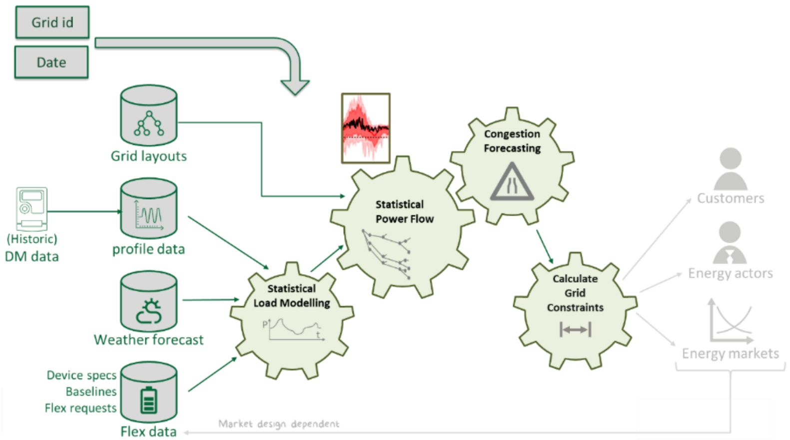
Pillar 2 Day-ahead LV congestion forecast

Partners: VITO

KER 8

Problem

DSOs have a very low level of observability in their LV network. Indeed, parts of the LV network are (almost) not measured nor monitored automatically, and as a result, it is hard to forecast what is likely to happen on the networks. Nevertheless, having a better view on LV networks is necessary for DSOs to being able to manage their assets better. The latter would lead to improved assets use and eventually lower costs for society. Furthermore, for flexibility markets to work properly, DSOs need to know where the congestion risks are, and thus, the needs for congestion management in their LV networks. Currently, the lack of measurements in LV grids makes it hard to estimate congestion risks, making it hard to further improve distribution grid management.



Solution

The LV congestion forecasting tool aims at calculating the risks for congestion on a LV distribution feeder for a forecasted day. These congestions are overvoltages, undervoltages or overcurrents anywhere within the feeder, or overloading of the MV/LV transformers. The tool does not deterministically calculate congestions, as for this calculation the necessary input would be impossible to acquire (e.g. deterministic forecasts of single connection consumption are not available), but merely outputs a congestion risk based on the statistically possible LV feeder states during the forecasted period. The congestion risks are defined as the probability a particular congestion may take place, and is based on a predefined risk threshold that is calculated per node and per time step. The calculations within the tool are based on historical, and (if available) recent grid and connection profile measurements, as well as weather forecasts. The tool assumes that the grid lay-out is known. However, the phase-connectivity of the single-phase connections is assumed to be unknown by the DSOs.

USP

The tool provides the congestion risk on a particular LV network, even when there are little to no measurements available on the given network. The only prerequisite of the tool is that the network topology must be known, since all other unknowns are covered through exploiting statistical methods to assess the congestion risk.

Value	Customer
Improved distribution grid management	DSO, society
Safe activation of flexibile assets on the LV network for ancillary services	DSO
LV congestion forecast, given sparse measurement data	DSO

KER 9

Pillar 2 Flexible dynamic line rating (FDLR)

Partners: ENERGA

Problem

RES energy producers have a connection agreement with the DSO in which a power limit is defined. In case the forecasted renewable power generation exceeds the defined power limit, RES will be curtailed. For most wind farms (WF), contractual connection capacity is lower than the installed capacity. This means that these WFs in windy conditions can deliver more power than agreed in the connection agreement. However, it is dependent on the HV line's allowable capacity in the given weather condition, which results from the safety of the line operation. The safety of the line implies that in every span, the distance to the earth should be kept within normative limits. The allowable line capacity can be calculated based on the traditional method called static line rating (SLR) where it is generally fixed depending on the season of the year, but it can also be done based on DLR (dynamic line rating). Using the traditional method implies that there is more curtailment of renewable energy, but also that new RES generators are waiting to be connected to the grid while the network is being reinforced.

Solution

The DLR-based flexible allowable capacity of the HV lines (FDLR) allows to provide flexibility to RES generators that have more forecasted renewable power generation than the defined power limit. As such, RES generators could buy flexibility services on the flexibility market from the DSO. DLR values are usually larger than SLR, leading to a better lines' capacity estimation and usage. As a result, FDLR can be used for operational planning by considering the changing capacity of the line due to thermal conditions. It can look at the full line capacity utilization and as such have a more efficient load dispatching, avoiding the so-called 'bottleneck' which provides safety for the overhead lines (OHL) operation. FDLR utilizes weather-based dynamic line rating (DLR) which is nowadays the only measure to cope with increased power transmission demand, especially in the situations when network infrastructure upgrading (for example restringing) is hardly possible. DLR is calculated based on the measured or forecasted weather conditions along the line (ambient temperature, wind speed, wind direction, and solar irradiance, and line parameters).

USP

The selling point of the tool is the high accuracy of the calculated results and low cost, especially when deployed for multiple lines. In practical deployment, when DLR values are used for short-term load flow and congestion analysis, the very accurate thermal model of the HV lines in the steady state is used. Presently the calculation accuracy of the wire location over the ground is better than +/-10 cm, as proved in the field installations. Accuracy of the wire location over the ground is very important for the safety of the HV line operation in terms of keeping the normative distance to the ground. There are very few companies that offer a similar solution.

Value	Customer
More accurate calculation of the wire location over ground	DSOs / TSOs
Adapted (higher) line capacity available for RES	RES producers
Less RES curtailment	Society

Pillar 5 Improved SRA method

Partners: Comillas

KER 10

Problem

Given that local flexibility markets are at an early development and implementation stage, there are many open research questions related to their design and implementation (e.g. flexibility product definition, clearing methods, DSO need determination, etc.). Answers to these questions are needed for policy makers and regulators to better understand the value of flexibility for policy and regulatory design as well as to evaluate investment plans, submitted by DSOs, integrating flexibility. Insights on these topics can ensure more efficient development of distribution grids and integration of DER thanks to proper designs of flexibility markets, can lower network costs and can ensure more efficient grid connections. Furthermore, they can ensure the availability of new knowledge on local market design for stakeholders and ensure data-driven conclusions that can support regulatory developments related to flexibility.

Solution

The improved SRA (scalability and replicability analysis) methodology and associated modelling tools aim to provide data-driven information on some of these open issues such as when and where flexibility is most useful or what the required conditions for it to be useful are. The methodology performs a simulation-based quantitative SRA of use cases related to applying local flexibility markets to prevent or alleviate distribution grid constraints. The aim of this type of SRA is to assess the impact on a certain number of Key Performance Indicators (KPIs) (e.g. grid constraints avoided, flexibility costs, etc.) of changes in several factors or boundary conditions relevant to upscaling and replication, i.e. grid characteristics (impedances, voltage levels, topology), existing grid users (load/generation profiles), and FSP characteristics (type, technology, flexibility availability, costs, location). These factors drive, on the one hand, the amount and type of flexibility needs by the DSO and, on the other hand, the capability and cost of the FSPs to solve them. Within EUniversal, new modelling capabilities have been developed for the methodology to enable a more efficient use of flexibility and the analysis of additional use cases. More specifically, the developments being made are: implement the full set of SRA tools within the same environment using Python language, joint use of active and reactive power, calculation of sensitivity factors for congestions based on a coupled AC power flow (DC power transfer distribution factors were used in previous implementations), comparison of market-clearing by a MO vs. DSO determined flexibility activations (involving different grid-modelling approaches), and solving congestions and voltage problems jointly.

USP

A key strength of this tool is its ability to combine modelling, regulatory and power systems expertise into a single methodology to evaluate the performance of use cases on local flexibility markets under different scales and contexts. The new developments include a result analysis and visualization module which supports the interpretation of results and decision-making based on them.

Value	Customer
Valuation of flexibility under different grid conditions	DSO
Testing of alternative market formulations	MO, platforms
Deeper knowledge on the value of flexibility	FSPs
Knowledge on flexibility	Engineering master and PhD students

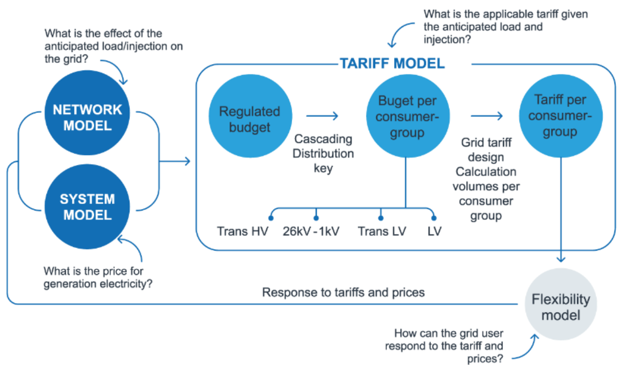
KER 11

Pillar 5 Method for dynamic grid tariff design

Partners: VITO

Problem

Higher flexibility needs require giving triggers to FSPs to offer flexibility at the right place and at the right time. To achieve this, well adapted grid tariffs are needed. However, it is hard to determine which tariffs are appropriate given the fact that there are many unknown and uncertain factors. There is a need for more transparency in the tariff design process and the criteria used to set tariffs. Grid tariffs need to be designed in such a way that they improve the efficient use of the grid and incentivize consumers to reduce grid congestion by shifting their peak consumption away from the peak demand periods. Properly designed tariffs could encourage consumers to step into demand response programs and could stimulate innovation.



Solution

This methodology helps DSOs, TSO, regulators, etc. to set up appropriate tariffs in an environment with many unknown and uncertain factors. It is a comprehensive methodology for the design of tariffs that can mitigate both short- and long-term congestions. It consists, firstly, of a qualitative analysis that incorporates a conceptual framework of establishing grid tariff designs which includes the different design dimensions, provides a review of dynamic tariff design methodologies and best practices, and studies the congestion needs that have to be addressed. Secondly, it consists of a quantitative analysis using a simulation environment consisting of different sub-models: a system model which represents the electricity system in clustered fashion, a network model which represents the distribution network, the tariff model which defines the selected tariffs, and the flexibility model which represents the (residential) demand on the level of individual consumers.

USP

VITO designed a comprehensive methodology which can be used to define and evaluate the impact of an alternative design of several electricity pricing components on the consumer, society and the electricity grid. By using the methodology developed, DSOs and TSOs are enabled to design dynamic grid tariffs which can provide an implicit flexibility signal to the residential consumer to adapt its behaviour in function of the grid state. Hence, by applying the methodology, implicit tariff signals could lead to reduced grid operation costs.

Value	Customer
Knowledge on tariffs and prices	DSOs, TSOs, NRA, policy makers
Methodology to assess LV flex for management of LV grid constraints	DSO, FSP
Method to design proper incentives for adaptive behaviour of consumers	DSO, FSP, consumers

Pillar 5 **Framework for flexibility quantification**

Partners: ENGIE Impact, INESC TEC

KER 12

Problem

DSOs may procure flexibility services, rather than reinforcing the grid, since this might be more timely and costly. However, the questions of when and how to organize such Flexibility Markets are still an open debate. We are not aware of such preliminary quantification exercises. These initiatives were not transparent on the framework used to assess future needs in flexibility, to characterize them or to define an appropriate LFM to procure required services.

Solution

For this reason, this KER performed optimal power flow simulations, in view of getting quantified and realistic insights on the available flexibility of distributed generation and flexible loads like water heaters, air conditioning, space heating equipment and EV chargers, and their impact on operational planning of the electricity network under different conditions. In particular, it was aimed to quantify the congestion and voltage issues that are expected to appear in a distribution grid characterized by increasing shares of intermittent RES generation and flexible loads. This was done by means of a methodology to assess the available flexibility in a distribution grid, and their impact on operational planning of the electricity network under different conditions. Based on simulations of a detailed electricity distribution grid, this methodology contributes to this discussion in two ways. First, it aims at characterizing the issues (mainly congestions and under- or over-voltages): when, how often, how long and where are issues happening. Second, it provides insights about the solutions and the interaction of assets located at different places in the grid (LV/MV in particular). The proposed methodology consists of a techno-economic optimization framework for the definition of flexibility products. The main characteristics of the product that can be identified are the type, location, capacity and duration of the flexibility. The model is an intraday optimization, that identifies congestion or voltage problems according to the nature of the network. It will run on an intraday basis to determine the optimal control that needs to be applied for the following day. The value of the KER is in the methodology to define the flexibility that can solve the congestions identified by an optimal power flow analysis.

USP

ENGIE Impact is able to combine modelling, regulatory and power systems expertise into a single methodology to evaluate the performance of use cases on local flexibility markets under different conditions (penetration of RES and EV charging stations). ENGIE Impact owns the required tool (multi-period optimal power flow on a distribution network). Some of the use cases are:

- Network configurations under different scenarios of RES and EV penetration.
- evolution of the network for the next 10+ coming years (2030, period to be considered for establishing the market)

Value	Customer
Characterization of network issues (when, where…)	DSO, FSP
Quantification of available flexibility and its impact	
Insights in how to design local flexibility markets	DSO, NRA, Policy
Helping define geographical scope of LFM	

KER 13

Pillar 3 Aggregation algorithms for local flexibility

Partners: Centrica, EON, E-REDES, NODES, N-SIDE

Problem

With the current regulation, there is a minimum quantity that participants need to be able to bid into energy markets before they can participate. Therefore, small volumes of flexibility cannot participate into the market without aggregation. This is a significant entry barrier. A solution is to aggregate multiple small-scale flexible assets to allow them to offer together a larger volume of (aggregated) flexibility. However, this leads to a portfolio with different residential and industrial, small- and large-scale assets combined which each face economic, technical and regulatory challenges needing to be accounted for during aggregation.

Solution

To aggregate resources optimally, Centrica designed an algorithm to aggregate small volumes of flexibility located in LV and MV grids to provide services for distribution system operators (DSO). This small volume of flexibility is located at end-user's premises. Centrica, as flexibility service provider (FSP), will aggregate the available flexibility from different flexible assets, such as batteries, electrical water heaters, or electric vehicles. This aggregation will be done not only to reduce the impact of uncertainty related to the energy consumption and behaviour of individual end-users, but also to meet the minimum flexibility required to participate in the market. In the EUniversal project, the aggregated available flexibility will be estimated and offered to flexibility market operators (FMO) via UMEI API. Depending on the market design and type market, the aggregated flexibility will be selected either by an FMO or a DSO afterwards to solve the grid constraint. The objective is to understand the DSO market better with different types of flexible assets. Previously, only batteries were considered, and during EUniversal hot water tanks and EVs were added.

USP

This aggregated flexibility will reduce the investment of the SO in grid expansion, potential curtailment of renewable energy assets or even prevent a black-out event. This algorithm will also help end-users to maximize their benefit from installing flexible assets and minimize their energy cost. It can model different types of flexible assets and calculate their available flexibility at each time step, aggregate it and offer it to the market while respecting end-users' comfort level. The algorithm consists of different parts: modelling of assets, optimization (min customer costs, or other OF) to calculate optimal bidding, constraints, (comfort level, max power that can be injected in grid...), and considerations for data driven methods of controlling the assets. Due to the lack of data, they will have a simpler MPC (model predictive controller).

Value	Customer
Enabling the participation of LV / MV customers	End-users, FSP
Solving the grid issues using aggregated flexibility	DSO
Participation in local flexibility market	FMO, DSO, FSP
Reduction of energy cost and greenhouse gases	Society, consumers
Reduce unnecessary grid investments	DSO, Society
Reduce market liquidity or supply issues	Society, DSO, policy

KER 14

Pillar 5 Business models and policy

Partners: Vlerick, E-DSO

Problem

There is a need to create knowledge and regulatory recommendations regarding the implementation of flexibility mechanisms in terms of regulation and business models. There are many tools available to implement flexibility, national and European regulations are not harmonized, and the trade-offs between the different options are not straight forward.

Solution

This KER consists of 1) regulatory recommendations and 2) Business model innovation and CBA methodologies. Regulatory recommendations are presented in 'D10.3 Regulatory recommendations for flexibility options and markets.' The deliverable shows how different flexibility mechanisms can be combined and discusses why regulatory sandboxes and market power remedies can be important for the optimal implementation of the mechanisms. Six flexibility tools are defined: flexible access and connection agreements, dynamic network tariffs, local flexibility markets, bilateral contracts, cost-based mechanisms and obligations. Business models are compared in 'D10.1 business model canvas and comparison of CBA methodologies. The deliverable analyses, first, the business models of the EUniversal demos before examining distribution planning methodologies in Europe. The business models are built using Osterwalder's business model canvas. Second, the deliverable describes the evaluation of distribution planning methodologies in Europe, with a focus on the trade-off between flexibility and network investments.

USP

Often, regulatory analysis is presented in reports on a country per country basis, making it difficult to evaluate the trade-offs in different flexibility or planning methodologies.

In the results mentioned above, a series of interviews and workshops with experts led to abstractions of the main building blocks behind the different tools used across Europe. This leads to a summarized bird's-eye view of the different flexibility tools available.

Value	Customer
Regulatory recommendations on implementation options of different flexibility tools	1/regulators, 2/stakeholders (DSOs, Flexibility service providers, market operators,...), 3/students and academics, 4/ public bodies
Flexibility market business models for different use cases tested in the project are outlined.	
Evaluation of distribution planning methodologies in Europe	
Comparison of sandbox methodologies	
Mitigation of rising network costs	

KER 15

Pillar 2 Day-ahead flexibility needs assessment

Partners: INESC-TEC, E-REDES, ENGIE Impact

Problem

Operating distribution networks with flexibility requires efficient tools capable of defining cost-effective day-ahead operation plans for DSO assets and flexibility. DSO requires tools to support the following steps:

a) Foreseeing grid issues, such as congestion and voltage problems and estimate flexibility needs. It is important that DSOs can enable the activation of a group of resources within a specific zone or by combining resources across multiple zones, to facilitate aggregation and enhance flexibility provision.

b) Selecting appropriate flexibility bids in response to forecasted issues (e.g. congestion and voltage problems).

Without fulfilling these needs, it is hard for DSOs to tackle grid challenges proactively to ensure a more efficient operation of their networks, to enhance grid efficiency, increase renewable energy penetration and demand response, and to ensure economic efficiency.

Solution

MV_FST is a computational tool designed to address and provide the flexibility within MV electric grids when grid issues are anticipated. The tool utilizes two distinct methodologies (a and b) to compute flexibility. The combination of these two methodologies allows MV_FST to accurately compute and offer the required flexibility in MV electric grids.

a) **Grid segmentation procedure**: This approach involves identifying zones within the grid based on sensitivity coefficients. These zones offer flexibility to effectively resolve foreseen grid issues like congestion management and voltage control.

b) **Optimization of flexibility bids**: This method focuses on selecting the optimal flexibility bids through a cost minimization process. By considering sensitivity coefficients, the tool selects the most suitable flexibility bids to solve the congestion and voltage constraints.

USP

Methodology a) segments the MV electric grid into distinct zones, enabling precise identification and communication of flexibility needs for each zone. This methodology ensures effective resolution of foreseen voltage and/or current issues on a zone-by-zone basis by computing the required flexibility of the grid buses. Furthermore, methodology a) identifies the optimal combination of grid zones that collectively provide the necessary flexibility to overcome grid limitations. By considering tuples of grid zones, the methodology ensures a holistic and coordinated approach to addressing grid challenges.

In methodology b) DSOs can leverage this feature to select the optimal bids that align with grid requirements and constraints. The utilization of this feature improves grid management and operational decision-making for DSOs.

Value	Customer
Enables the quantification of flexibility needs in MV networks through zones	DSOs/Aggregator
Enables the quantification of flexibility needs in MV networks through combination of zones.	DSOs/Aggregator
Computationally efficient for running in close to real-time	DSOs/Aggregators/Commercial market parties

KER 16

Pillar 2 MV and LV coordinated control

Partners: INESC TEC, ENGIE Impact, E-REDES

Problem

A great majority of flexibility resources will be connected at the LV network. They can help solve local problems in LV networks or can be aggregated to help solve grid constraints at the MV networks. This interaction requires a better coordination between the operation of MV and LV networks and in future AMDS tools developed for MV and LV network management.

Solution

The MV and LV coordinated control methodology enables DSO procurement of day-ahead market-based flexibility services for congestion management and voltage control. An iterative procedure is adopted for enabling LV flexible resources to help solving technical constraints in the MV network, while ensuring that no further technical problems result from flexibility provision. It involves the coordination of different tools developed within the project that forecast the network status and expected MV and LV network constraints (voltage violations and congestions), estimates the flexibility needs in both MV and LV networks and defines the optimal selection of bids, if necessary. Besides ensuring the safe mobilization of aggregated LV resources for MV operation support, it also considers that MV network optimization would also solve some of the restrictions detected in LV networks. It also enables the selection of flexibility bids considering the impact of flexibility mobilization in both LV and MV network. This framework is compatible with different market designs, both continuous or auction based, with day-ahead and/or intraday activity.

USP

It is a management framework enabling DSO procurement of day-ahead and/or intraday market-based flexibility services for congestion management and voltage control for both MV and LV networks. To date, ADMS applications are mainly focused in MV and HV networks. LV network applications are mainly focused on Outage Management and fault location. This framework effectively coordinates different tools designed specifically for LV networks and MV networks.

It is compatible with different market designs. The framework has been tested and adapted to the NODES and N-side market designs. From the N-side design, where the clearing is done on the platform, privacy is maintained while network limits are communicated and respected. From NODES the bid selection is done from the DSO side with full network knowledge.

Value	Customer
Promotes coordinated control between MV and LV networks	DSO
Define operating envelopes at the MV/LV substation	DSO
Better market & grid integration	DSO
Unlocking local flexibility (demand side flexibility) potential	FSP

KER 17

Pillar 2 LV Phase and Topology Mapping tool

Partners: INESC-TEC, KUL

Problem

By having a better view on the LV networks, DSOs are able to manage their assets better, leading to improved asset use and eventually lower costs for society. However, currently, there is a lack of metering equipment meaning that either crew field interventions are need, or more investments are needed in additional metering equipment (which takes time and is expensive). One specific part of the required information is phase connectivity identification (PCI), enabling better knowledge of system conditions. This is valuable for operation and planning of an active distribution network due to improved distribution network (DN) topology information leading to (1) Improved grid asset utilization, (2) Flexibility activation for congestion/voltage unbalance mitigation, (3) Providing network awareness for charging of EVs, operating heat pumps, DER, storage etc. (4) Higher renewable integration & improved forecasting, (5) Formation of active DN, (6) Accurate unbalanced power flow studies and OPF calculations crucial for operational and planning of DNs, (7) Detecting topology changes due to DN reconfiguration, and (8) More accurate digital twin formation for evaluating in time ahead and real time. Phase connectivity information is therefore crucial for DN operation and resource planning. In absence of this, either manual phase connectivity identification (PCI) is performed or using expensive hardware which often requires sensor placement at the reference point and in the premises of single-phase consumer. Both these methods are intrusive and expensive.

Solution

In our work, we utilized historical voltage time series information for PCI. Voltage magnitude is measured by most smart meters and other measurement devices either already existing or economical to be installed. Further, for highly accurate phase identification, our PCI methodology does not require the distribution network to be fully observable. Thus, the proposed methodology would imply significant savings for the system operators. For instance, in the UK there are 11 million distribution network feeders. Performing PCI for these feeders would cost multiple millions if not billions of euros. The LV phase and topology mapping tool performs the phase identification of the LV consumers and estimates the topology and electrical characteristics of the LV distribution networks, avoiding the need for human intervention to characterize the LV network. Two different algorithms were also developed by INESC TEC and KUL considering different data availability scenarios. INESC TEC scenarios consider that most of the LV consumers are equipped with smart meters, while KUL ones consider lower levels of observability in the distribution network.

USP

It is a data-driven tool designed for LV networks which doesn't require the installation of additional measurement equipment or field crew mobilization, since it takes advantage of existing information such as smart metering and other existing measuring infrastructure.

Value	Customer
Enables the identification of phases and characterization of network topology and electrical characteristics without intervention in the field.	DSO

KER 18

Pillar 2	MV network maintenance planning tool	Partners: INESC TEC, E-REDES

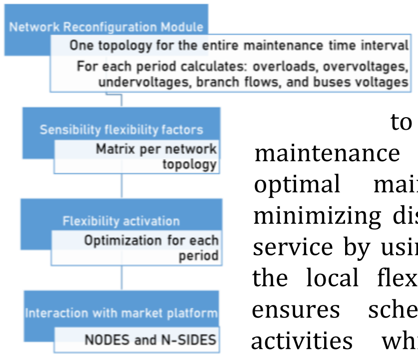
Problem

Maintenance can cause comfort issues to the end-customers, flexibility can mitigate the discomfort of maintenaince for consumers. Individuals and businesses need to have reliable access to electricity, reducing the inconveniences caused by unexpected outages. By utilizing local flexibility markets, maintenance can be scheduled during periods that are less expensive, such as avoiding costly Sunday mornings when maintenance crew costs are higher. The challenge is to plan this in an efficient way to ensure the minimization of both cost DSO costs, and increase the network reliability (which is good for overall economic growth and competitiveness).

Solution

The MV network maintenance planning tool is a decision support tool to help network operators to plan network reconfiguration actions required to ensure service to a maximum number of consumers and taking into consideration the participation of flexible resources through voltage and congestion management services. The tool identifies alternative network topologies for a configurable time frame (e.g. a set of days) selected by the operator, considering the network area out of service due to maintenance. Then if technical problems are identified, the flexibility needs are quantified. The possible alternatives of periods for maintenance are then ranked according to pre-defined KPIs (cost, interruption time interval, amount of flexibility mobilized, number of switching actions, etc.).

USP



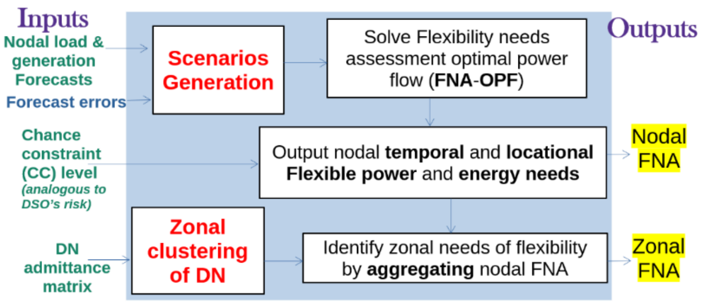
The selling point of the MV network maintenance planning tool is its ability to support network operator maintenance planning, recommending optimal maintenance actions while minimizing disruptions to end customer service by using the flexibility offered in the local flexibility markets. This tool ensures scheduling the maintenance activities while reducing costs and maximizing the availability and reliability of the network for customers.

Value	Customer
Network topology optimization	DSO
Identification of network congestions	DSO
Use medium to long-term flex. in NODES and N-SIDE	DSO
Support network operator maintenance planning	DSO
Improved network reliability and availability	Society
Reduced downtime contributes to economic growth	Society

Pillar 2 | **Low Voltage Flexibility Needs Assessment** | **Partners: KUL** | **KER 19**

Problem

Flexibility needs assessment (FNA) refers to the amount of flexibility the DSO needs to plan or procure from the flexibility market to avoid probable Distribution Network Incidents (DNI). There is a need to quantify flexibility needs for a distribution network in order to avoid probable congestion incidents. DNIs in low voltage grids are often local problems in which flexible resources in the proximity may be enough to avoid these incidents.



The probable DNI are captured using uncertainty modeling and scenarios generated with Monte Carlo techniques that emulate the different events which could happen. The scenario generation utilizes the nodal load and generation forecast along with historical forecast errors. A flexibility needs assessment-optimal power flow (FNA-OPF) problem is solved for each of the scenarios. The robust FNA, considering the worst-case scenario, if used for flexibility procurement would lead to substantial over-procurement. In order to avoid this, a risk-based index, e.g. a chance constraint (CC), is introduced. Higher values of the CC would indicate greater risk the DSO might have to encounter by facing unresolved DNIs.

Solution

USP

Time ahead temporal and locational quantification of the flexibility needed to avoid probable distribution network congestion or power quality deterioration incidents. Customizing the above feature for different grid topologies, with different levels of observability is hard to do in traditional power system analysis. Current software companies are not flexible enough to adapt to new needs.

Value	Customer
Forecasting of LV network congestion	SO, MO, software co.
Quantification of locational and temporal flexibility needs	DSO
Improved network operation	DSO