edgeFLEX

D1.1

Scenario description for dynamic-phasor driven voltage control for VPPs

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Abstract

The Virtual Power Plants (VPPs) concept is increasingly spreading among the networks and among electrical utilities. This deliverable starts from the basic definition related to VPPs to pave a basic and shared knowledge of the topics discussed in edgeFLEX. Afterwards, the voltage control scenario, which applies on VPPs, is presented and detailed. This description offers a solid and clear environment in which the voltage control service can be tested and assessed.

Keyword list

Virtual Power Plants; terminology; state of the art; scenario; use case; KPI; voltage control;

Disclaimer

Executive Summary

This deliverable can be considered the first report of WP1. Furthermore, it is the first deliverable describing the world of VPPs and their use cases and scenarios. In particular, D1.1 starts with an overview of the state of the art regarding VPPs and of services developed within their framework.

Afterwards, the focus moves towards those VPPs concepts that are of interest to the edgeFLEX project. An overview of the terminology adopted within the project is provided. This terminology will be used by all partners and in all future deliverables.

After the theoretical parts have been presented, D1.1 continues by introducing the dynamic-phasor driven voltage control scenario to the reader.

The use cases defined within the dynamic-phasor driven voltage control scenario have been developed with the aim of fulfilling the requirements and needs of both the customers and prosumers and of the distribution system operators or utilities.

D1.1 is intended to be read before D1.2 and it should be read before any other deliverables submitted in month 12 to enable the reader to better understand them and to progress logically with the reading of those deliverables.

D1.1 produced input for WP3 and WP4, and established the basis for the field trial implementation within WP5. Finally, WP6 is going to gather information from WP1 and D1.1 to prepare their solution for the edgeFLEX results adoption.

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Table of Contents

1. Introduction

This document presents the preliminary results obtained within WP1 and in particular of Task 1.1. The reader will be guided by this first deliverable through the technical concepts at the core of the edgeFLEX project. Therefore, the document can be considered the first deliverable which should be read to provide readers new to the edgeFLEX project with a better understand the logic and the mechanisms behind a complex project such as edgeFLEX.

A complete overview of published research on Virtual Power Plants (VPPs) defining the state of the art acts a starting point for the work of the project. Definitions and standards are fundamental to distinguishing between which concerns edgeFLEX research and innovation will investigate and those issues which can be considered to be marginal.

The overview of existing solutions led to the development of an ad hoc voltage control scenario for the project. The scenario consists of several use cases which cover a variety of potential real in-field configurations, involving both the massive or modest presence of renewable energy sources (RES).

1.1 Objective of the report

The report aims at introducing the technical and electrical perspectives of the edgeFLEX project. In particular, it provides to the reader a basic knowledge on the VPP subject, focusing on what has been done until now. Afterwards, the report clearly defines a technical terminology accepted and shared among the partners, which background is heterogeneous and various. Finally, the main goal of the report is to present the developed scenario and use cases associated to the voltage control service tackled in the project.

1.2 Outline of the report

The first part of the report is dedicated to the literature review and definition of VPPs. They have been studied from both the academic and standard perspectives to provide a broad overview of knowledge on this topic.

The second part of the report is dedicated instead to the project terminology and definitions.

The third and last part contains the voltage control scenario and the associated uses cases, which treat different aspect and configurations of the grid involving RES.

1.3 How to Read this Document

This report can be read as a standalone document. However, the interested reader can refer to the following deliverables to get a better overview of the concepts and services developed within the edgeFLEX project.

- D1.2 - Dynamic-phasor driven voltage control concept for current VPPs in large scale deployment (M12) [1]: in this deliverable the algorithm for the edgeFLEX Voltage control service is described.
- D4.1 - Description of EdgeFLEX platform design (M12): detailed information on the overall edgeFLEX platform, where the inertia estimation is integrated as a service, can be found in [2].

2. VPP state of the art

2.1 The Virtual Power Plant

2.1.1 Definitions

A virtual power plant (VPP) is a cloud-based distributed power plant that aggregates heterogeneous distributed energy resources (DER), either renewable or not, to create a unique entity for the purposes of enhancing power generation, as well as trading or selling power on the electricity market. The heart of a VPP is an Energy Management System (EMS) which coordinates the power flows coming from the generators, controllable loads and storages.

We move from an energy system with centralized power plants operated by large utilities, towards a blend of decentralized and frequently sustainable energy production in small facilities. Those little scope plants are regularly possessed by little organizations or families, who become prosumers (consumer and producer at the same time). The way the network is operated must be then re-evaluated and our frameworks overhauled. The unpredictability of inexhaustible sources like sun and wind do not really imperil the framework balance as long as they are managed properly. Furthermore, that is actually where a VPP comes in.

A VPP is a network of decentralized, medium-scale power generating units such as wind farms, solar parks, and Combined Heat and Power (CHP) units, as well as flexible power consumers and storage systems. Any decentralized unit that consumes, stores, or delivers power can turn into a piece of a VPP. The interconnected units are managed through the central control room of the VPP but nonetheless remain independent in their operation and ownership. Moreover, to working each individual resource in the Virtual Power Plant, the central control system utilizes a special algorithm to conform to adjusting hold orders from transmission system operators and to grid conditions – similarly as a bigger, ordinary power plant does. Besides, the Virtual Power Plant can respond rapidly and productively with regards to exchanging power, in this manner altering plant activities as indicated by value signals from the power trades.

The goal of a VPP is to smooth the peaks on the grid by sagaciously dispersing the power generated by the individual units during times of maximum load.

2.1.2 Objective of a VPP

The goals of a VPP rely upon the market conditions in which it operates. All in all, the point is to arrange disseminated energy resources (regularly sustainable power source resources like sun based, wind, hydropower, and biomass units) just as adaptable power buyers (also called demand response or demand side management) and capacity frameworks so as to screen, conjecture, improve, and dispatch their age or utilization. By being aggregated into a VPP, the assets can be forecasted, upgraded, and exchanged like one single power plant. That way, variances in the generation of renewables can be adjusted by varying here and there the power generation and the power utilization of controllable units. Incorporating sustainable power sources into existing markets is another essential target of a VPP. Individual little plants can as a rule not give adjusting administrations or offer their adaptability on the power trades. This is on the grounds that their generation profile changes too unequivocally, or they basically don't meet the base offer size of the business sectors.

The flexibility, which means the fast and adaptable capacity to adjust the grid, is among the best qualities of VPPs and their most eminent distinction contrasted with traditional power plants. VPPs can use the total power to respond to changes of the power cost on the trades, rapidly adjusting to the current inventory of power in the grid, and along these lines execute exchanges. All things considered, the cost of power changes continually, up to 96 times each day in intra-day exchanging on power trades.

2.1.3 Benefits for the energy sector

The idea that the future is digital can be extended to the energy sector. The way electricity is supplied is undergoing a fundamental shift, not only on a national, but also on a global scale.

There is the new tendency of abandoning large and fossil-fuelled power plants towards smaller and decentralized units that are linked together thanks to the digital wave. Similar to car sharing services without a car fleet and hotel booking platforms that do not own hotels, VPP are a breakthrough for the power supply. VPP operators do not own power plants; they just optimize the way in which every linked asset – still owned by a third party – is used. What we have already achieved, up to date, is that VPPs have already exceeded the aggregated capacity of the largest nuclear power plants by far, and in the process, they produce climate-neutral power from the networked assets and address challenges that the power markets will face soon.

2.1.4 VPPs and Microgrids

With the introduction of VPPs, one may confuse them with microgrids. The concept of microgrid is more physical; it refers to a small portion of network of a specific area and with a defined set of assets operating in it. What's more, they can disconnect from the main grid to act as islands of power. A VPP instead is a more abstract concept with a high level of flexibility and with the aim of managing and providing services for the portion of network over which it operates. On the contrary, microgrids do not always provide services to the main grid.

2.1.5 VPPs and Energy Communities

An Energy Community (EC) can be considered the alter ego of a VPP from the customer perspective. In fact, EC are legal energy entities which main partner is the customer/prosumer who acts and gets involved in the energy field. The aim of an EC is to involve all actors into a community indeed, to make people aware of their role in the energy field. Furthermore, the EC aims at providing environmental, economic or social community benefits for its members or the local area and in an even better case providing benefits to its members by balancing the needs of both customers and electric operators. In other words, the EC may be seen as a small utility which stakeholders are families, small producers, SMUs, municipalities and interested people.

2.2 Standards

The VPP concept is something new that includes several other existing topics, definitions and assets. Therefore, there are no dedicated Standards yet, to fix and define all aspects related to VPPs. However, most of the actors that contribute to constitute a VPP, have been standardized during the years [3].

For example, Standard IEEE 1547 [4] "Requirement for DER grid interconnection and interoperability" is a pillar for VPPs studies, because it is fundamental to properly integrate renewables with the grid and its assets. The 1547 series contains several documents addressing test procedures, design guides, and suggested methodology for the correct operation of DER within the power network.

Turning to another standard, IEEE 2030 series [5], "Smart Grid Interoperability Standards and Transportation Infrastructure" addresses smart grid interoperability with storage systems, microcontrollers, and microgrid controllers.

Due to their huge spread in the last few years, electric vehicles are always considered when VPPs are studied. Therefore, their associated Standard IEEE 2040 [6] "Connected and Automated Intelligent Vehicles" is among those to analyse when the studied VPP involve electric vehicles.

Finally, in term of communication, the most appropriate standards to deal with VPPs are IEC 61850 [7], IEC 61970 [8], IEC 6235 [9], etc.

2.3 Examples of VPPs

2.3.1 Hydro-Power Plants in Romania

The authors presented in [10] a VPP developed in Romania. The aims were to reduce the voltage fluctuations, the prediction errors penalties, and to participate in the power market. To this purpose, an area suitable for the installation of small and medium hydro-plants has been found and selected for the VPP implementation.

The critical part consisted of integrating the new renewable sources into the existing grid; however, after an in-depth preliminary study and assessment, the hydro-plant construction was completed.

Afterwards, three different tests were performed to test the effectiveness of the VPP:

(i) the renewables management without VPP coordination, but with the conventional way.
(ii) as described in the previous test (i) but using the VPP coordination.
(iii) In this test, more DER were added along with the reactive power control feature for the VPP.

From the results it emerged that the presence of the VPP coordination allowed to significantly reduce the load peaks and the discrepancies between the power generation and the consumption, confirming the effectiveness of the VPP presence, and its impact on flexibility.

2.3.2 A distribution network in Germany

In [11] a German VPP has been developed to assess whether or not it was possible to manage the active and reactive power of a portion of a distribution grid. The VPP consists of 5 small hydro power plants and 1 storage system. The EMS collects the voltages measured at the network nodes and it compute some calculation to assess if active and reactive power exceed the given limits. The power evaluation allows the operator to consequentially adjust the voltage values by acting on the hydro power plants production.

This kind of evaluation is performed in 4 different ways:
(i) without any control (hence without the VPP);
(ii) controlling only the active power;
(iii) controlling only the reactive power;
(iv) controlling both powers.

Of course, the first solution can be used as a reference because it does not involve a VPP; hence, it is the perfect reference for a VPP evaluation.

The authors report in the results how the presence of a double control on powers allows the operators to have an enhanced control on the voltage stability of their networks, proving the applicability and effectiveness of implementing a VPP solution.

3. VPP integration in edgeFLEX

3.1 Project terminology

This section is dedicated to introducing the terminology that is being adopted by the consortium. The need for a shared terminology came considering the variety of the partners' background, which is not necessary the energy or the ICT sector. Therefore, to align ideas and to avoid any misunderstanding from the very beginning of the project, the edgeFLEX terminology is presented here.

Looking at Figure 1, it is possible to understand how the VPPs scenarios are going to be structured and developed.

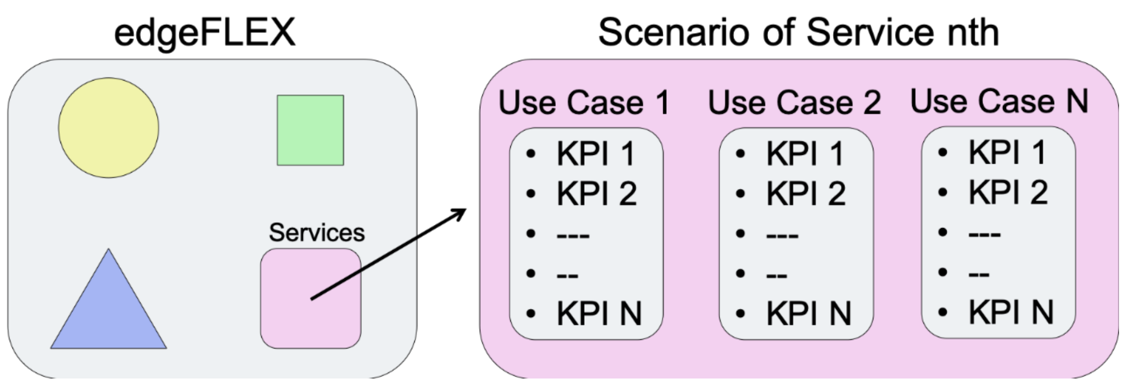

Figure 1 edgeFLEX services structure

edgeFLEX will provide services to be implemented in VPPs. For example, the dynamic-phasor driven voltage control is one of them. Each of the services is described by one scenario that provides a general overview of what that service is about. Within a scenario, several use cases are included to implement the service into a specific context or application.

The peculiarity of a use case is its specificity in treating a particular aspect of the service; e.g. the application of the dynamic-phasor driven voltage control to a benchmark network of IEEE. Finally, the assessment and the performance of the service are evaluated, in each use case, through KPIs. Each KPI, which may vary from one use case to another, refers to a specific parameter or feature of the network that has been chosen to help the evaluation of the service. As an example, the latency of the communication in a particular network, or the reactive power of an electrical asset, are two parameter that can be chosen for being a KPI.

Summarizing, the performance of a service, described by its scenario, will be evaluated through the KPIs defined in each use case. The set of use cases selected for each service aims at covering the wider range of potential applications of the service itself.

3.2 Voltage control Scenario and Requirements

This section briefly introduces the voltage control strategy that has been implemented in WP1 for the integration in the edgeFLEX architecture. Further details on the algorithm implementation can be found in deliverable D1.2.

3.2.1 Voltage Control Scope and Objectives

Electric distribution grids currently need to accommodate Distributed Generations (DGs) consisting mainly of Renewable Energy Sources (RESs). The speed of this change will drastically increase in order to phase out the fossil power sources in favour of RESs. DG integration can be challenging in case generation capacity exceeds several times the peak load, resulting in technical issues for the distribution grid defined as overvoltages and overloads. Even though reinforcing the grid (e.g., replacing substation transformers or laying additional cables) has been the most often applied solution by Distribution System Operators (DSOs), increasing grid digitalization offers the possibility to DSOs to implement smart tools to control the grid, being less invasive and more environmentally friendly. Voltage control architectures have been recently developed to find optimal or sub-optimal solutions to control a portion of the distribution grid, obtaining better performances than would be achieved using classical droop-like classical local controllers [12]. Moreover, since voltage regulation is to some extent a truly localized problem, voltage control algorithms that solve an optimisation problem seem to be an appropriate candidate to regulate distribution grid voltage. From a technical perspective, the implementation of the control requires the implementation of a measurement infrastructure. The voltage control implemented in the context of WP1 uses PMU measurements such as voltage and power and, if available, power measurements from devices installed in the network and then uses this data as input for the algorithm.

3.2.2 Voltage control scenario

There is one scenario considered for D1.1 that deals with the control of the resources owned by the DSO in a portion of a distribution grid. The main objective is to control the voltage by using the DGs that can be directly controlled by the DSO without interfacing with the market.

The researchers of WP1 consider the results of the scenario applicable for the implementation in a distribution grid where the DSO has its own resources installed.

3.2.2.1 General description of the use cases

The voltage control scenario is developed at the DSO level and it considers generation provided by DGs installed in the distribution grid. Since the generation units can be Photovoltaics (PVs) or Energy Storage Systems (ESSs) the use cases that have been defined are the following:

- Use Case 1: Impact of DGs penetration in creating over-voltages
- Use Case 2: Mixed control with PVs and ESSs
- Use Case 3: Dynamic change of the devices under control

The three Use Cases are described in the following subsections.

The controllable variables that are considered for the calculation of the set-points are:

- Active Power curtailment of PVs: This variable reduces the amount of active power injected by the PVs
- Reactive Power curtailment of PVs: This variable controls the reactive power injections of the PVs
- Active Power of the ESSs: This variable controls the active power injections of the ESSs

The voltage control is performed at the DSO MV substation using the voltage measured in different points of the grid and power measurements collected from the DGs. The component requirements for the voltage control algorithm are defined as follows:

- DGs: Installed PVs and ESSs that can receive active power curtailment or reactive power set-points.
- Measurement devices: edgePMUs should be installed in the nodes of the distribution grid to measure the voltage. DGs should be able to provide power measurements, to provide to the voltage algorithm the information on the available power to be used to calculate the set points.
- Voltage control service: running at the substation of the DSO to collect the measurements data and run the control algorithm.
- Powerflow service: To perform simulation of the grid to verify the consequences of applying the set-points on the electrical network.

3.2.2.2 Scenario Diagram

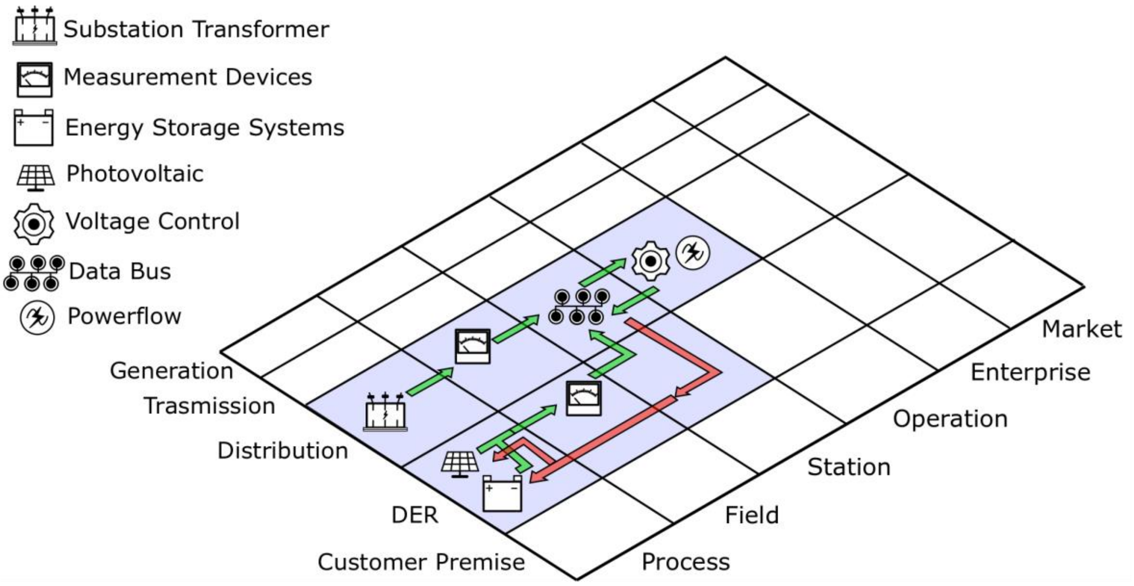

Figure 2 Voltage Control Diagram

The diagram in Figure 2 shows the different components of the voltage control scenario placed in the Zones and Domains composing the Smart Grid Architecture Model (SGAM). This allows the identification of the different components of the scenario highlighting also the interconnections.

Based on the diagram, the measurement devices placed at the substation and at the DERs, provide voltage and power measurements to a data concentrator, a Data Bus, which aggregates the data and performs the conversion to the proper format. At the operation level, the voltage control runs the algorithm and calculates the power set-points. Based on received measurements and on the calculated set-points the Powerflow simulates the grid to verify the outputs of the control algorithm before applying them.

3.2.2.2.1 KPIs

The KPIs used in the proposed use cases are:

- **KPI-1**: Amount of reduction (%) of overvoltage during the day
- **KPI-2**: Amount of reduction (%) of active power curtailment
- **KPI-3**: Number of PVs that receive active power curtailment set-points

3.2.2.3 Use Case 1: Impact of DGs penetration in creating over-voltages

In this first use case we use a 40 nodes low voltage (LV) distribution grid to demonstrate the impact on the voltage profiles of the increasing installation of uncontrolled DGs in the electrical grid. The KPI used for this use case is only **KPI-1** since no control set-points are applied.

3.2.2.4 Use Case 2: Mixed control with PVs and ESSs

On the same grid used for Use Case 1, the voltage algorithm is performed in 3 different conditions:

1. Only active power curtailment is applied
2. Active power curtailment and reactive power control of PVs are applied
3. Active power curtailment, reactive power control of PVs and active power control of the ESSs are applied.

In this case **KPI-1** is used to show the positive impact of applying the voltage control, whereas **KPI-2** and **KPI-3** are used to demonstrate the reduction of active power curtailment when the number of control variables increases.

3.2.2.5 Use Case 3: Dynamic change of the devices under control

The last use case verifies the ability of the voltage algorithm to receive external messages that define the nodes (active nodes) participating in the control of the grid used in the other use cases. Here the KPI used is **KPI-2** to show the variation of the amount of active power curtailment when the active nodes change during the day.

4. Conclusion

This report has introduced the reader to the world of VPPs. Starting from the literature, without forgetting the standards perspective, VPP elements and characteristics have been defined and commented.

Turning to the core of the report, a set of definitions has been provided to develop a project terminology that applies to all deliverables and which is to be used by all members of the edgeFLEX consortium. This choice allows the partners to avoid misunderstandings during the work on tasks and enables us to create a common vision among the partners.

The VPP introduction in the first part of the document has been used to design and develop a voltage control scenario for the project. The scenario consists of 3 use cases, each of which deals with a specific aspect of the network. Use Case 1 verifies how DG penetration affects the voltage stability. Use Case 2 tackles the voltage control when both PVs and ESSs are among the grid. Use Case 3 includes in the voltage control the possibility of changing in real time the set of assets that participate to the regulation of the voltage.

The implementation and results of this Use Cases is described in D1.2 [1].

5. List of Figures

6. References

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7. List of Abbreviations

VPP	Virtual Power Plant
DER	Distributed Energy Resources
CHP	Combined Heat and Power
EC	Energy Community
PV	Photovoltaic
ESS	Energy Storage System
DSO	Distribution System Operator
DG	Distributed Generator
LV	Low Voltage
MV	Medium Voltage