May 2020

Deliverable D1.1: Flexibility at the distribution grid: Reference usage scenarios for market and system operation services

The project Flexible Energy Production, Demand and Storage-based Virtual Power Plants for Electricity Markets and Resilient DSO Operation (FEVER) receives funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement no 864537.

Project name	**FEVER**
ID & Title	D1.1 - Flexibility at the distribution grid: Reference usage scenarios for market and system operation services
Work package:	WP1 – Analysis of flexibility measures and correlation with the distribution grid operation
Contractual delivery date:	31.05.2020
Actual delivery date:	15.06.2020
Main responsible:	Alexios Birbas, UP
Security:	PU
Nature:	R
Version:	v1.0
Total number of pages:	90

Authors and reviewers	
Main responsible:	Evangelos Karfopoulos – Intracom Telecom, evkarf@intracom-telecom.com
Author(s) / contributor(s):	ICOM, Isidoros Kokos
	ICOM, Victror Alkalais
	ICOM, Nikos Ioannidis
	ICOM, Isidoros Kokos
	ICOM, Ilias Lamprinos
	UP, Konstantinos Nikolaos Andriopoulos
	UP, Athanasios Bachoumis
	UCY, Christina Papadimitriou
	UCY, Panagiotis Bountouris
	UCY, Marios Kynigos
	INEA, Saso Brus
	INEA, Zoran Marinsek
	EST, Luisa Candido
	UdG, Joaquim Melendez Frigola
	UdG, Joan Colomer Llinas
	UCL, Anthony Papavasiliou
	UCL, Ilyes Mezghani
	UPC, Ruecker, Fabian
	UPC, Andreas Sumper
	UPC, Francesc Girbau i Llistuella
	SWW, Gerhard Meindl
	HEnEx, Konstantinos Oureilidis
	HEnEx, Emmanouil Bakirtzis
	HEnEx, Aikaterini Forouli

BAUM, Rita Dornmair
BAUM, Ludwig Karg
BAUM, Anna Maaß
AAU, Torben Bach Pedersen
FlexShape, Laurynas Siksnys
Es-geht, Christopher Schneider
IBM, Emanuele Ragnoli

Reviewer(s): Ilias Lamprinos, Intracom Telecom

Abstract

The scope of this document is to define use cases within the FEVER project where flexibility from distributed energy resources is leveraged and exploited for supporting network operation under normal and critical conditions. The definition of the use cases comprises two steps: the business analysis, where the business actors involved and the business objectives served are identified; and, the technical analysis where the needs for tools and services that enable the extraction and trading of Distributed Energy Resource (DER) flexibility are identified.

Keyword list

flexibility, trading, network congestion, voltage compensation, flexibility markets, energy community, p2p trading, microgrid, grid islanding, dynamic prices

Executive summary

The realization of the energy transition in the context of traditional electricity grids provokes significant operational challenges to the electricity grid System Operators and requires a drastic modification in the way electricity grids are designed, planned and operated. The reinforcement and extension of distribution networks is not always the most efficient and cost efficient solution to respond to energy transition's challenges. Distributed Energy Resource (DER) flexibility (i.e. dispatchable loads, manageable distributed generation units, battery storage units, electric vehicles, etc.) is an alternative which can be exploited by DSOs to complement grid reinforcement.

Complementing network reinforcement with the exploitation of flexibility services will result in higher welfare for all the energy related actors, DSOs included. The role of the DSO towards flexibility products is clearly framed by the Council of European Energy Regulators "*as user who purchases flexibility services from third parties but he does not provide it"* aiming to: i) to optimize distribution network capacity investments, ii) to reduce technical losses, iii) to reduce curtailment of distributed generation and outage times and iv) to increase distributed generation hosting capacity.

There are different models for describing the coordination mechanisms enabling DSOs to access flexibility. Their adoption and implementation may vary significantly depending on the national policies and regulatory framework. The different models can be divided into four categories i) rules-based approaches, ii) network tariffs, iii) connection agreements and iv) market-based procurement.

The scope of this document is to define a set of use cases where flexibility from distributed energy resources is leveraged and exploited for supporting the distribution level network operation under normal and critical conditions.

The definition of the use cases comprises two steps: the business analysis, where the business actors involved and the business objectives served are identified; and, the technical analysis where the needs for tools and services that enable the extraction and trading of Distributed Energy Resource (DER) flexibility are identified.

For the realization of the use case analysis, a methodology introduced by the IEC 62559-2:2015 standard was adopted. Standard use case documentation templates were exploited, taking into account the business orientation and specifications of the FEVER project pilots.

As a first step of the use case analysis, all the involved actors and their interactions were recorded and the FEVER Role Model was formed by properly considering and extending the Harmonized European Electricity Market Role model defined by ENTSO-E.

The second step of the use case analysis comprises the definition of the business objectives and the business goals of the identified business FEVER actors. The targeted domains identified are: the DSOs' domain where the primary aim is to defer grid reinforcements and enhance network operational efficiency/security/resilience; the Market Operators' domain where the primary aim is to provide the market mechanisms that facilitate the trading of flexibility at all levels of distribution grid; and, the Flexibility Service Providers' domain where the primary aim is to leverage flexibility from DERs towards grid and market oriented flexibility services.

The third step of the use case analysis entails the definition of the technical use cases which enables the partial or complete realization of the aforementioned business use cases. The definition of the technical use cases comprises the identification of tools/services that are needed for enabling the realization of one or more business use cases.

This document details FEVER approach for the above steps.

Finally, this deliverable includes a discussion section with FEVER's approach towards addressing the operational concerns and flexibility needs of the distribution grid as these were identified by E.DSO.

Table of contents

List of Tables

List of figures

List of abbreviations

Abbreviation	Term
AMI	Advanced Metering Infrastructure
BA	Bidding Application
BRP	Balance Responsible Party
BSP	Balancing Service Provider
BUC	Business Use Case
CAPEX	Cpaital Expenditure
CEER	Council of European Energy Regulators
CEF	Critical Event Forecaster
CEPA	Critical Event Prevention Application
Con	Consumer
DAMSc	Day-Ahead Market Scheduler
DAMSDA	Day-Ahead Market Schedule Disaggregation Application
DER	Distributed Energy Resource
DLT	Decentralized Ledger Technologies
DMS	Distribution Management System
DSO	Distribution System Operator
E.DSO	European Distribution System Operators
EC	Energy Community
ECM	Energy Community Member
ECMO	Energy Community Market Operator
ECR	Energy Community Responsible
EF	Energy Forecaster
EMS	Energy Management System
EV	Electric Vehicle
FA	Flexibility Aggregator
FMO	FEVER Market Operator
FMS	Flexibility Management System
FP	Flexible Prosumer
FSCA	Flexibility Service Consuming Agent
FSP	Flexibility Service Provider
FSPA	Flexibility Service Providing Agent
FTP	Flexibility Trading Platform
GIS	Geographical Information System
GOP	Grid Operation Planner
HLUC	High Level Use Case
IDFTM	Intra-Day Flexibility Trading Mechanism
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IPMA	Island Power Management Application
ISO	International Organisation for Standardization
LMO	Local Market Operator

LRA	Loss Reduction Application
MgFMS	Microgrid Flexibility Management System
MgM	Microgrid Member
MgMO	Microgrid Market Operator
MgR	Microgrid Responsible
MO	Market Operator
NDPA	Network Data Processing Application
OLTC	On-Load Tap Changer
OPEX	Operational Expenditure
P2P	Peer-to-Peer
P2P-FTP	Peer-to-peer flexibility trading platform
PCG	Party Connected to the Grid
PED	Power Electronic Device
PFS	Power Flow Simulator
PQS	Power Quality Service
PUC	Primary Use Case
PV	Photovoltaic
RES	Renewable Energy Source
RM	Remuneration Mechanism
RMO	Regional Market Operator
RTBMM	Real-Time Balancing Market Mechanism
SCADA	Supervisory Control And Data Acquisition
SDS	Switchgear Dispatch Scheduler
SG	Switchgear
SGAM	Smart Grid Architecture Model
SHA	Self-Healing Application
SO	System Operator
Sub-DSO	Sub- Distribution System Operator
SUC	Secondary Use Case
TSO	Transmision System Oparator
UC	Use case
UML	Unified Modelling Language
VCA	Voltage Compensation Application
WF	Weather Forecaster

1. Introduction

The FEVER project is a response to the call *LC-SC3-ES-1-2019, entitled "Flexible Energy Production, Demand and Storage-based Virtual Power Plants for Electricity Markets and Resilient DSO Operation"*, of the Horizon 2020 program. The FEVER's project objectives lie on three keys axes:

1. To implement flexibility measures and comprehensive flexibility aggregation, management and trading solutions, in order to provide electricity grid services, such as congestion management and overvoltage avoidance, at the distribution grid.

2. To implement enhanced monitoring and automated control of the distribution grid, by developing an innovative toolbox and implementing advanced technology that leverages flexibility form distributed resources towards providing ancillary services.

3. To implement market mechanisms and tools that support and incentivize flexibility services. These mechanisms concern different market structures and time-horizons (day-ahead and continuous trading of flexibility services, centralized and local/regional markets).

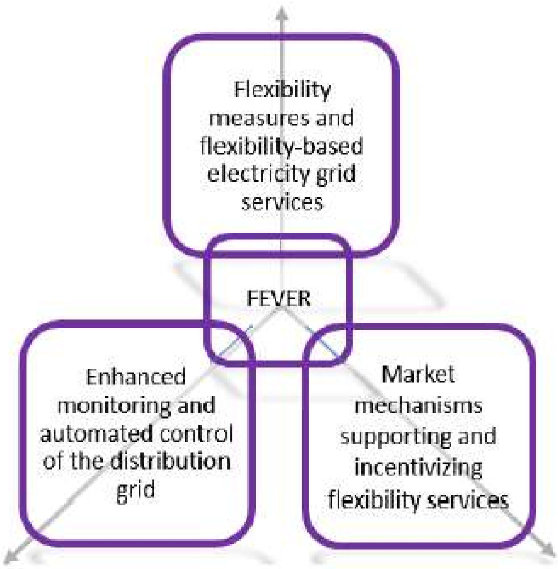

Figure 1: FEVER's high-level scope.

In order to demonstrate the real-world applicability of the innovation concepts and to create a strong impact of the results, FEVER includes three real-world pilots in different countries, namely Cyprus, Germany and Spain. In addition to that, the project includes a simulation testbed to be designed by HEnEx, i.e. the electricity Market Operator in Greece, to simulate the operation of electricity markets that incorporate novel flexibility-related services. In each demo activity, different specific objectives are set, overall contributing to the accomplishment of FEVER's high-level objectives.

1.1 Scope and objectives of this deliverable

The objective of this deliverable is the coherent and detailed definition of use case scenarios that are relevant to the FEVER project. These cases and their identified actors are aligned with the FEVER pilot sites' needs, expectations and framework of operation. A high level of maturity in the definition of all the uses cases is being realized, facilitating the requirements' analysis and cyber-physical systems' architecture definition, at sub-sequent phases of WP1 evolution.

1.2 Outline of the deliverable

Addressing the main objectives of the project, this document is structured as follows. Section 2 describes the flexibility concept at the distribution grid. Firstly, in 2.1 the distribution grid challenges arising in the new era of power systems are analyzed. In particular, we present the developments in the network design, planning and operation due to energy transition and then what are the main challenges that DSOs face. The way that DSOs can leverage the flexibility is described in 2.2. This section answers the questions of how a DSO can benefit from flexibility, which are the state-of-the-art flexibility mechanisms adopted today, what are the requirements and characteristics of DSO's flexibility needs, and lastly, which is the regulatory framework governing the exploitation of flexibility from DERs. In section 2.3 we provide a summary of the existing flexibility mechanisms which can be used by the DSOs. Section 3 incorporates the use case analysis of the FEVER project. Specifically, 3.1 and 3.2 present the methodology followed for the use case description and the actors involved in the different pilot sites, respectively. Finally, the business and technical use cases encapsulated in the FEVER project are incorporated in subsections 3.3 and 3.4. After all the aforementioned sections, the report summarizes the main conclusions in Section 4.

1.3 How to read this document

The content of this report is of interest for technical staff (e.g. software architects, requirements engineers) who want to understand the scope, objectives and integration aspects of FEVER project and/or to proceed with the detailed design of the FEVER tools. It is also of interest for domain experts who seek for innovative scenarios of flexibility usage, capable to be transferred in other projects. The document can be read without prior knowledge of any FEVER specific documentation.

2. Flexibility in the distribution grid

2.1 New challenges for the distribution grid operators

The concerns regarding the increase of the global average temperature impose significant challenges in the energy sector. According to the "*CO2 emissions from fuel Combustion*" report published by the International Energy Agency (IEA) [EFFC] energy and transportation sector are the major pollutant factors representing nearly two third of the global emissions. The exploitation of alternative environmental-friendly energy resources, e.g. the increased share of renewable generation in the energy mix and the electrification of transport sector, can combat the climate changes.

On the other hand, the realization of the energy transition in the context of traditional electricity grids provokes significant operational challenges to the System Operators and requires a drastic modification in the way electricity grids are designed, planned and operated (Figure 2).

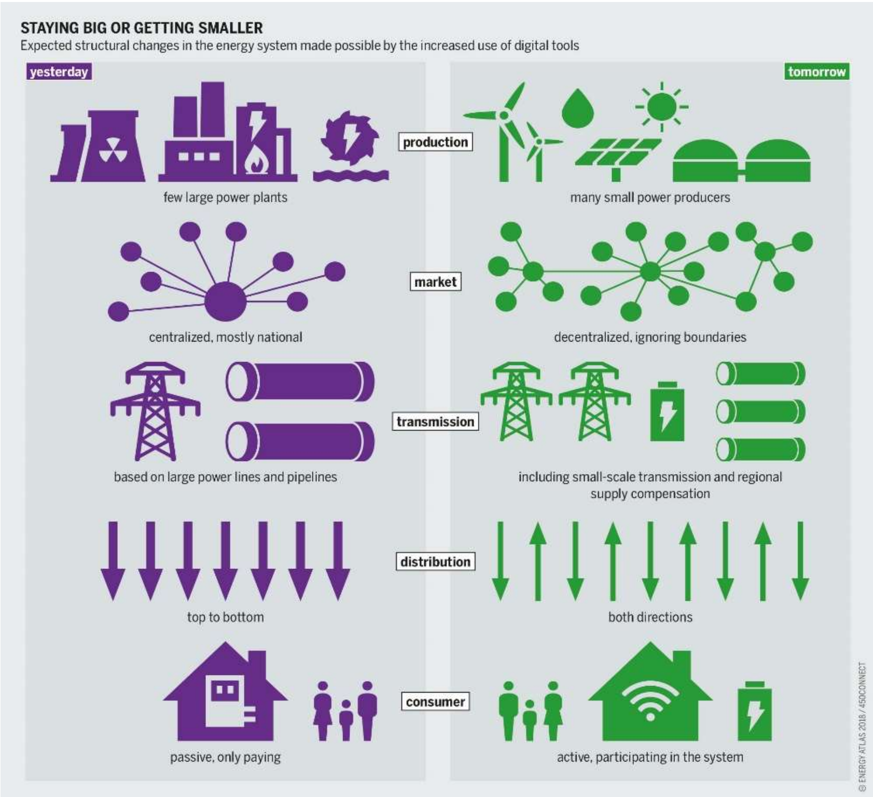

Figure 2: Comparison of conventional and future electrical networks (Source: https://en.wikipedia.org/wiki/Smart_grid)

The traditional operational framework of electricity grids adopts a centralized approach with the principal assumption that the distribution of energy follows a top-down approach, i.e. from the central conventional power plants connected to the upper voltage level of electricity grid to the consumption connected to the lowest voltage levels of the grid. The operational principle of this approach is that the system production should follow the consumption profile towards achieving the energy equilibrium. This centralistic approach results in long power paths such that the most distant consumption points are supplied by the generation centers. The increased electrical distance between electrical generation and consumption implies reduced energy efficiency in terms of energy losses, voltage quality, energy costs, etc.

The decarbonization and the decentralization of the energy generation dictate new grid operational principles. Increasing the Renewable Energy Source (RES) share in the overall generation mix of the electricity grids means predominantly increasing generation capacity connected to the lower voltage levels which introduces significant uncertainty in the generation profile due to their intermittent production. In light of this, the conventional operational principle of electricity grids is changing such that (flexible) consumption follows the dynamic generation profile for achieving the energy equilibrium. The integration of RES into electricity grids, especially at distribution level close to consumption, can contribute to the reduction of the electrical distance between consumption and production enabling a more efficient network operation.

As current distribution networks are characterized by a significant “structural inertia” with passive loads and dispatchable distributed generation, a high penetration of distributed RES may provoke significant network operational issues. The main operational issues, as identified by [CRTB], are:

- **Violation of thermal limits**: The integration of DER modifies the current flows, which can lead to the violation of thermal limits of network elements.
- **Voltage regulation**: High DER production combined with low consumption may lead to overvoltage problems at remote nodes of the lines. Even though voltage regulation is achieved through on-load tap changers (OLTC) and step voltage regulators (VR), voltage control is complicated when lines with different characteristics are supplied from the same transformer.
- **Fault current level**: DER contribution to fault currents may result in exceeding the short capacity of the network.
- **Power quality**: Power electronics’ interfaced DERs provide harmonic emissions.
- **Reverse power flow**: Distribution networks are designed on the assumption of unidirectional power flows. Under minimum demand and maximum DER generation conditions, reversal of power flows affects certain types of tap changers and the operation of voltage control and protection schemes.

Due to these adverse effects on distribution network operation, DSOs adopt conservative measures and appear to be reluctant to allow high RES penetration levels. In light of this, DSOs have introduced a metric named “RES Hosting Capacity” which indicates the maximum power capacity of distributed RES that can be integrated in a distribution network above which one or combination of network specific parameters (e.g. bus voltage, line thermal limit, network losses, fault current, etc.) exceed the pre-defined limit imposed by international standards and/or regulatory frameworks. This metric highly depends on the network specifications and RES distribution along the network buses.

An indicative sensitivity analysis of the distributed RES impact on the network operation is illustrated in Figure 3. As the RES installed capacity increases (horizontal steps) and considering diverse RES allocation scenarios among network busses for each RES capacity (vertical steps), three operational areas can be identified by DSOs when considering grid infrastructure capacity for hosting RES:

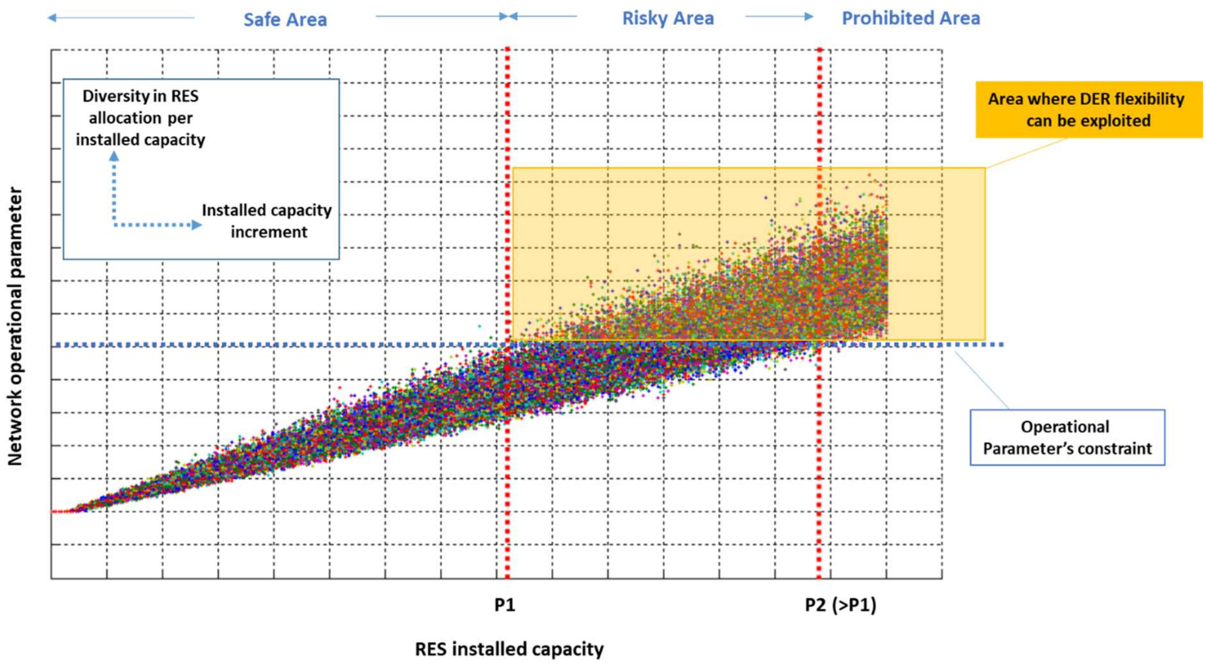

Figure 3: Sensitivity analysis of the RES deployment impact on distribution network operation (Source: http://artemis.cslab.ece.ntua.gr:8080/jspui/bitstream/123456789/9077/1/PD2017-0009.pdf)

- **Safe area**: Any RES installed capacity (lower than threshold P1), irrespectively of its distribution among network buses, can be hosted by the present grid infrastructures without provoking violation of any network operational constraints.
- **Risky area**: Depending on the RES capacity allocation scenario, a specific RES deployment level (between threshold P1 and P2) may raise network operational issues. The risk of network constraint violation increases as the installed capacity increases.
- **Prohibited area**: Any RES installed capacity (higher than threshold P2), irrespectively of its distribution among network buses, violates network operational constraint(s).

The yellow area illustrated in Figure 3 is indicative of the network operational limitations on the RES hosting capacity. Such network operational limitations can be eliminated by proceeding to costly network reinforcement in order to maintain the secure and reliable network operation. The exploitation of DER flexibility as an alternative can prove to be beneficial for both the System Operator and flexibility providers given its economic viability compared to network upgrade.

Apart from the challenges raised by the high RES deployment level at distribution grid level, System Operators should also get prepared for handling the demand requirements of future energy loads such as plug-in Electric Vehicles (EVs). The integration of EVs into distribution grids adds an additional load to the network demand curve. Due to the EVs' mobility, this demand is highly dynamic in terms of spatial and temporal characteristics. Despite this, the charging demand should be served by System Operators without any discrimination compared to the conventional one.

The mass penetration of EVs into existing distribution networks may cause several concerns regarding the effects of this new type of load on their planning and operation. Several studies highlight the potential network operational issues which might be raised when the integration of EVs into electricity grids is realized via the "plug-n-charge" concept (i.e. charging process starts as soon as EV is plugged-in). One of the key findings of these studies is that home charging, which is the major charging option for EV users, increases or produces new peak load since the EV charging demand is synchronized with the high household consumption when EV users return home from their last daily travel. Such increased network demand peaks can provoke voltage excursions or grid infrastructure overloading. Voltage constraint violations are expected in rural networks, in the buses farthest from the feeding points, due to their long radial lines. On the contrary urban networks have short lines serving increased consumption and, thus, they are more prone to face branch/transformer overloading issues faster than voltage drops. The network operational issues become more intense as the EV penetration level increases.

In respect to the existing infrastructures, each distribution network can host up to a maximum number of EVs without violating any network operational constraint. The maximum number of EVs that can be safely integrated in a distribution network depends on its technical and operational characteristics as well as on the charging scheme adopted by EV users (i.e. uncontrolled charging – "dumb", tariff-based smart charging, advanced smart charging – "valley-filling").

Figure 4 presents some indicative outcomes of the EV grid impact analysis performed within the framework of EU project MERGE[1]. The illustrated results are indicative on how EV flexibility can be exploited towards more efficient exploitation of network capacity. It is true that EVs remain idle during the largest period (>90%) of the day. During non-commuting period, EV charging demand can be shifted in order to avoid peaks of charging demand. EV flexibility can be exploited always considering EV users' preferences and mobility constraints and should be beneficial for both System Operators (technical/financial perspective) and EV users (financial perspective).

[1] https://cordis.europa.eu/project/id/241399

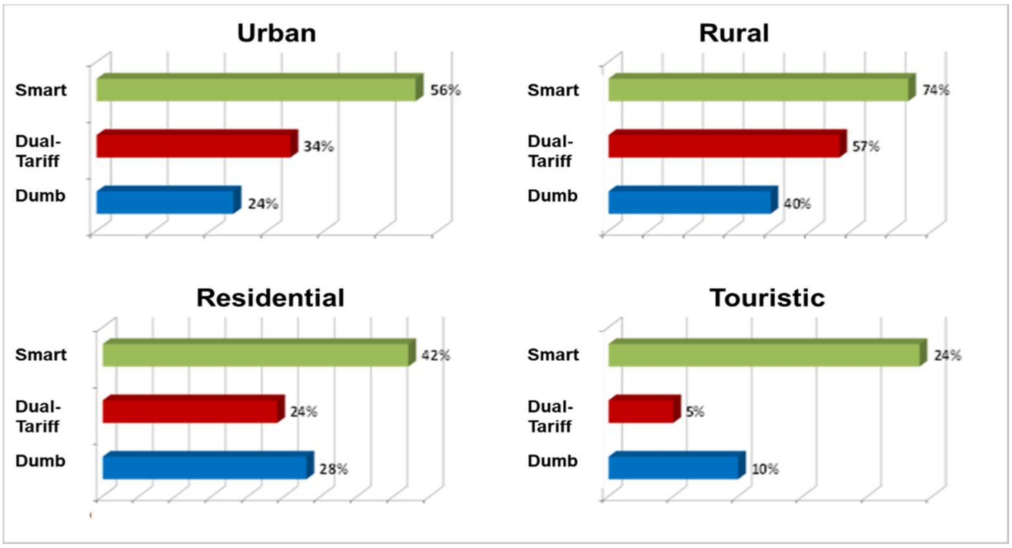

Figure 4: Indicative outcomes on the EV hosting capacity of distribution networks [IEVG]

2.2 Flexibility as a service for DSOs

The energy transition promoted by the EU and national policies dictates the decarburization and the decentralization of the energy generation. As a consequence, a large portion of the consumption in the electricity grids is expected to be served by renewable energy production. The stochasticity and volatility introduced in the generation profile due to RES intermittency necessitate additional efforts from System Operators in order to maintain the secure and reliable network operation, since the energy flows will be less predictable in the future grids. System operators must ensure the operational quality of the electricity grids either with or without the presence of RES.

It is expected that the number of distributed RES units connected at the distribution grid level will significantly increase in the upcoming years. This evolution will pose significant challenges to Distribution System Operators' (DSOs) ability to perform its core responsibilities of network operation management and grid stability. More specifically, in areas with low consumption, where the integration of large RES capacities will result in high RES surplus, distribution networks will need to be reinforced and extended. The reinforcement and extension of distribution networks is not always the most efficient and cost viable solution to respond to energy transition's challenges. DER flexibility (i.e. dispatchable loads, manageable distributed generation units, battery storage units, EVs, etc.) is an alternative which can be exploited by DSOs to complement grid reinforcement.

The European Distribution System Operators (E.DSO) have identified the benefits of DER flexibility exploitation for the network operational efficiency and security [DSOF]. E.DSO has adopted the following notion of flexibility, in respect to Eurelectric definition in Flexibility and Aggregation:

Flexibility is defined as the modification of generation injection and/or consumption patterns, on an individual or aggregated level, in reaction to an external signal (price signal / network tariff / activation) in order to provide a service within the energy system. The parameters used to characterize flexibility include: the amount of power modulation, the duration, the rate of change, the response time, the location etc.

Complementing network reinforcement with the exploitation of flexibility services will result in higher welfare for all the energy related actors, DSOs included. However, the exploitation of flexibility capacity by System Operators must be realized within a context that avoids any market distortion. It is essential to be ensured that DSOs remain neutral and they are sufficiently unbundled from the interests of flexibility providers. The different sources of flexibility, varying from demand response to storage and generation, should be given equal possibilities to provide arrangements for the provision of flexibility. The role of the DSO towards flexibility products is clearly framed by the Council of European Energy Regulators (CEER) "as user who purchases flexibility services from third parties but he does not provide it" [CFDL]. Simultaneously, flexibility services should be provided not only to System Operators but also to other actors in the power system domain. It might happen that the flexibility needs of DSOs for maintaining the secure and reliable network operation coincides with the flexibility needs from market players. In such case, there should exist advanced coordination flexibility mechanisms to allocate the available flexibility capacities where it is most valuable to society as whole and not just for commercial gain (E.DSO view on [DSOF]).

In this respect, E.DSO introduces a fundamental distinction between flexibility used by market players and flexibility used by Network Operators [DSOF].

- Market players always refer to activities performed with a commercial interest in mind, and actions focused on satisfying the energy needs of customers.
- Network Operators always refer to DSOs and TSOs, which are regulated companies and pursue an objective of efficient grid planning and operation. The use of flexibility is related to security of supply and quality of service. In other words, flexibility may help System Operators to keep the lights on when the grid is pushed to its limits.

To differentiate the aforementioned two types of flexibility services, the E.DSO introduced the term "***system flexibility services***" for defining the services delivered by market parties and procured by DSOs aiming to maximize the security of supply and the quality of service in the most efficient way. Table 1 summarizes the differences between flexibility used by commercial parties and DSOs.

Table 1: Difference between flexibility used by commercial parties and regulated DSO [DSOF].

Party	Activity	Business Model based on	Will procure	Flexibility use	Final aim
Commercial Party (supplier, aggregator, balance responsible party)	Buy and sell electricity (MWh) in a market	Price set by market rules	Portfolio Optimization	System-wide	Profit maximization
Regulated party - Distribution System Operator	Channel electricity between generators & consumers	Regulatory mechanism to cover costs[2]	System Flexibility Service	Local, regional or national	Grid planning and operational efficiency maximization

System flexibility services can be exploited in the whole chain of DSOs activities: planning, connection, access and operation. Existing European regulation encourages system flexibility services for such activities and this is reflected to the EC's consultation for the development of Network Codes & guidelines (2020-2023) [ECNC], where demand side flexibility along with cybersecurity are considered as main pillars for the development of the new Network Codes.

The potential added value of flexibility services towards more efficient electricity grids, as identified by E.DSO [DSOF], lies in the following aspects:

- **Optimized distribution network capacity investments**: *In cases of high generation or demand of electricity, parts of the electricity grid can be subject to congestion due to a limited distribution capacity. Network operators traditionally fix this issue by investing in network reinforcements. Using flexibility can help to defer an investment or could solve congestion when reinforcing the infrastructure would not be possible. If flexibility prevents an investment, the value of flexibility then equals the CAPEX and OPEX of the avoided reinforcement. If flexibility services enable the DSO to defer investments, the value of flexibility can be calculated as the avoided return on capital cost over the deferral duration.*
- **Reduced technical losses**: *Transport of a kWh from generators to consumers creates network losses (power dissipation in distribution lines and transformers) which are proportional to the length of the electricity route. Flexibility services can help to reduce losses. Network losses are already*

[2] The procurement of services, maybe market-based or not, but in the end the DSO always cover its cost according to a specific mechanism defined by a national (or regional) regulation.

given a value. The value of flexibility then corresponds to the amount of electricity that has not been lost.

- **Reduced curtailment of distributed generation and reduced outage times**: *By using flexibility services, DSOs could better control voltage profiles in areas with a high number of variable sources of electricity. Flexibility can, thus, directly benefit grid users (e.g. solar panel owners) who would be able to feed-in more energy to the grid. The value here is determined by avoided investments and maintenance costs in voltage control.*
- **Increased distributed generation hosting capacity**: *This point is related to the previous. By helping to keep the network stable, flexibility services could, in some areas, increase the distributed generation hosting capacity of the grid. The value here is also determined by avoided investments and maintenance costs in voltage control.*

One of the key aspects for enabling the system flexibility services to become a success story is the provision of a coherent regulatory framework at EU and member state level. CEER's view on this topic entails that the regulatory framework should enable the development of full range of possible flexibility services with discrete distinction of the flexibility exploitation between market actors and System Operators. The regulatory framework for DSOs should be non-discriminatory and not hinder or unduly dis-incentivize DSOs from facilitating the development of flexibility. Further details on the role and responsibilities of DSOs should be determined at national level, given the diversity of situations, legislation and needs across EU Member States and varying nature of DSOs (e.g. size and location).

2.3 Models enabling DSOs to access flexibility

There are different models for describing the coordination mechanisms enabling DSOs to access flexibility. Their adoption and implementation may vary significantly depending on the national policies and regulatory framework. A detailed analysis on the flexibility models can be found in FEVER deliverable *D4.1 "Flexibility-related European electricity markets: Modus operandi, proposed adaptations and extensions and metrics definition"*.

The different models can be divided into four categories as presented in Table 2 [CFDL]:

- **Rules-based approaches** – codes and rules which impose detailed flexibility requirements, ex. curtailment of RES production imposed by the dynamic constraints of the system operation in non-interconnected islands.
- **Network tariffs** – tariff schemes reflecting the real impact of the demand of network users on the grid operation and encouraging them to modify their consumption profile for a more efficient exploitation of the network capacity.
- **Connection agreements** – DSOs could reach agreements with customers for the provision of flexibility where a Member State considers this an appropriate measure. For example, in the case of transport electrification, DSOs proposed the concept of "dynamic grid capacity contracts" against the grid impact of EVs' charging demand. Such contracts imply that the contracted maximum allowable power at the connection point is not static but it varies reflecting the network operational conditions (similarly to the Time-Of-Use tariff schemes). The maximum allowable power is reduced when network is stressed while it increases during off-peak hours.
- **Market-based procurement** – DSOs can explicitly procure flexibility that benefits the grid services from the market(s). The flexibility could be procured via (bilateral) contracts or in "flexibility" market, e.g. via a platform or other forms of interfaces.

The latter category, i.e. market-based procurement, can be further categorized considering the level of cooperation between the distribution and transmission System Operators. Each market-based procurement category defines the System Operator's responsibilities and the interaction framework between the relevant flexibility stakeholders.

Table 2: Models enabling DSOs to access flexibility

Market-based procurement							Non Market-based procurement		
Separate DSO & TSO platforms		Combined DSO/TSO platforms			Integrated Market Model	P2P trading Market	Rules-based Approach	Network Tariffs	Connection Agreement
Contracts	DSO operated local flexibility market	Centralized market with DSO prequalification	Common TSO/DSO Market	Multi-layer TSO/DSO coordination					

✓ <u>**Market-based procurement sub-categories**</u>

Different market mechanisms exist facilitating the provision of flexibility services from flexibility providers located either at transmission or distribution network. The following market procurement mechanisms can be considered [CMTD]:

- **Separate DSO and TSO platforms:**
    - **Contracts** which are pre-defined bilateral flexibility agreements engaging DER owners to provide flexibility whenever it is requested by the DSO for supporting network operation.
    - **Local flexibility market** operated by the DSO**.** DERs located at the distribution system are offered first to the local flexibility market where the only byer is the DSO. The local flexibility market is supported by a trading platform that aims to match the spatio-temporal flexibility requirements of DSOs and the flexibility capacities offered by the flexibility providers (prosumers or flexibility aggregators).
- **Combined DSO/TSO management platforms**
    - **Centralized market with DSO prequalification,** provides a common market for flexibility services for resources connected at both transmission and distribution level. This market is operated by the TSO, who is also the only buyer. Consequently, all flexibility providers from distribution grid are contracted by the TSO for flexibility provision. In this respect, DSOs are not allowed to procure local flexibility but they are entitled to prequalify the utilization of the flexibility capacity of a DER located at distribution system. The prequalification process by the DSO ensures that the activation of resources from the distribution grid by the TSO does not violate operational constraints in the distribution grid (ex. congestion).
    - **Common TSO/DSO market** provides a common market platform for flexible resources connected to the transmission and distribution grid. All flexibility bids are offered and cleared in one market session considering transmission and distribution network constraints, simultaneously. Even though such a market mechanism ensures the exploitation of available flexibility capacity, irrespectively of the grid level where it is located, the optimization problem is large and it requires complex mathematical processing techniques.
    - **Multi-layer TSO/DSO coordination** enables a more decentralized organization of the market. In this case, a separate local market operated by the DSO, for local DSO needs, runs initially considering local grid constraints but without any formal commitment to the market participants. These preliminary results are shared with the TSO market and they are integrated in a second market optimization which outputs the final accepted bids and from whom (both for the DSO and the TSO)
- **Integrated market model**

A common flexibility market for regulated and non-regulated actors where flexible resources from the transmission and distribution network are considered. In this market model, a direct competition is allowed among regulated and non-regulated actors and the flexibility is allocated to the one with the highest willingness to pay. An independent Market Operator is required in order to ensure neutrality. The DSO prequalification phase can also be considered in this market model.

- **P2P trading markets**
  This is a novel market approach where distributed trading of flexibilities is realized on the basis of distributed ledger technologies. Flexibility providers can share their available flexibility capacities in a peer-to-peer transaction basis without the need of a market broker. The trading is done through a secure platform and all transactions are public and cannot be altered in any way creating, thus, full transparency.

3. Use case analysis

3.1 Methodology

3.1.1 Introduction

The development and integration of new functionalities in engineering systems requires a proper analysis and definition methodology in order to enable the successful identification and understanding of their technical requirements. Specifically, for delivering novel Smart Grid functionalities in terms of combining software-based together with hardware-based advances, the Use Case (UC) approach has been proven to play a very central part, having been used over the past years in numerous projects.

There are several standardization activities aiming at providing the fundamental definitions, templates and guidelines, e.g. the ISO/IEC 19505-2:2012, the IEC 62559-2 standard series and the CEN/CENELEC/ETSI Smart Grid Coordination Group Grid Architecture Model (SGAM) Framework. A Use Case (UC) defines the necessary actions performed by a system that will provide an impact. The impacts should be of interest for certain stakeholders (meaning that they are in line with their business goals) and should be measurable through specific metrics that are formulated in conjunction with the UC analysis and development procedure. More specifically, a UC based methodology should describe in a practical but precise manner the interactions amongst the various actors of the system that will facilitate the accomplishment of the objectives of the relevant functionalities which are going to be deployed in the system. Moreover, it should capture all the functional requirements of the respective process or function, as well as other related non-functional requirements (e.g. performance, security and interoperability) and in general ensure a common understanding of the functionality for all the stakeholders. This way, the collaboration and coordination between them is supported and their ability for further extending the developed functionalities is safeguarded.

In FEVER project, the analysis and development of the project UCs adheres to the methodological principles presented in IEC 62559-2:2015 standard "Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list" [UCTM]. The template of the standard was adjusted to the scope of the project, and is presented in Annex A.

3.1.2 Terminology

The basic UC-related terminology that is used throughout this document is as follows:

- **Use Case:** According to the Unified Modelling Language's (UML) specification [OUML] it is "the specification of a set of actions performed by a system, which yields an observable result that is, typically, of value for one or more actors or other stakeholders of the system".
- **Actor**: According to the same standard, an actor specifies a role played by an external entity that interacts with the subject (i.e. a system). This entity can be a human user of the designed system, or another system, application or device.
- **Party**: Legal entities, i.e. either natural persons (a person) or judicial persons (organizations) that can bundle different roles according to their business model.
- **Role:** Represents the intended external behaviour (i.e. responsibility) of a party. Parties cannot share a role. Parties carry out their activities by assuming roles, e.g. system operator, trader. Roles describe external business interactions with other parties in relation to the goal of a given business transaction e.g. Balance Responsible Party, Grid Operator, Market Operator.
- **Relationship:** Represent the interrelations between parties or roles (logical connections such as: association, aggregation, generalization, etc.)

3.1.3 Classification of Use Cases

The description of a system functionality can be approached from different perspectives. Usually, a higher-level perspective is considered, which models the business interactions between the stakeholders, i.e. a Business Case (BC). The business case omits the technical interactions and emphasizes on the business scenario (or scenarios) that aims at reaching the goals of the functionality to be developed. Following the definition of the higher level UCs and provided that general agreement has been reached amongst all the interested parties regarding the high-level goals of the new function, the UC developers identify and model the lower-level requirements and interactions between the systems that implement the various roles of the involved actors (i.e. usually referred to as technical actors).

In this respect, the design and actual deployment of complex applications, such as novel Smart Grid functionalities require modelling of the UCs from different design perspectives as well as levels of abstraction [SGRA]. In this context, the design scope defines the boundary box of the use case, i.e. tries to tackle questions of the general form: “what is in?”, “what is out?” for the system under design. On the other hand, the different perspectives regarding the levels of abstraction refer to the details in describing the objective(s) of the Use Case. In a similar way, the level of granularity refers to the different perspectives that UC-related information can be organized along with the level of detail at which they should be written.

An interesting classification of the UCs is presented in [SGCG], according to which:

- **Use case concepts (or High-Level Use Cases - HLUC)** describe a general idea by defining the roles (generic actors) involved and sketching their responsibilities but not the underlying business models or processes. The target audience is system engineers, business developers, regulators and key experts in standardization having a very good overview on the whole Smart Grid landscape.
- Conceptual business requirements are refined in one or **several business use cases** written by business architects or regulators which describe them within an enterprise scope (i.e. the operation of businesses) and the interaction between different roles, e.g. to contract or negotiate services.
- Refinement of the technical view is added by specifying one or multiple **device/system use cases** to realize the goal of a business use case. For these technical use cases we can define the device/system boundaries and interactions between the system(s) and external actors to fulfil a goal for the actor(s).

Furthermore, from a more technical point of view a device/system UC can take the form of [SGCG]:

- **Primary Use Case:** A primary use case (PUC) is a UC implemented in a specific system characterized by a defined boundary. In addition, it can be considered a tool for reaching one (or many) goal that are described by High-Level UCs. It should be noted that a HLUC can comprise various PUCs while the same PUC can be employed by various HLUCs with regard to the given goals and the specificities of the system to be developed.
- **Secondary Use Case:** Accordingly, a Secondary Use Case (SUC) is considered to be one level lower (more granular and less abstract) and describing core functionalities that are used by multiple PUCs.

When for the same PUC, various parameters can significantly alter the impact of the application, different Use Case Scenarios can be defined as a way to capture the diverse behaviors due to the different trigger signals or operational conditions. The classification described in this subsection for the UCs analysis and description is schematically presented in Figure 5.

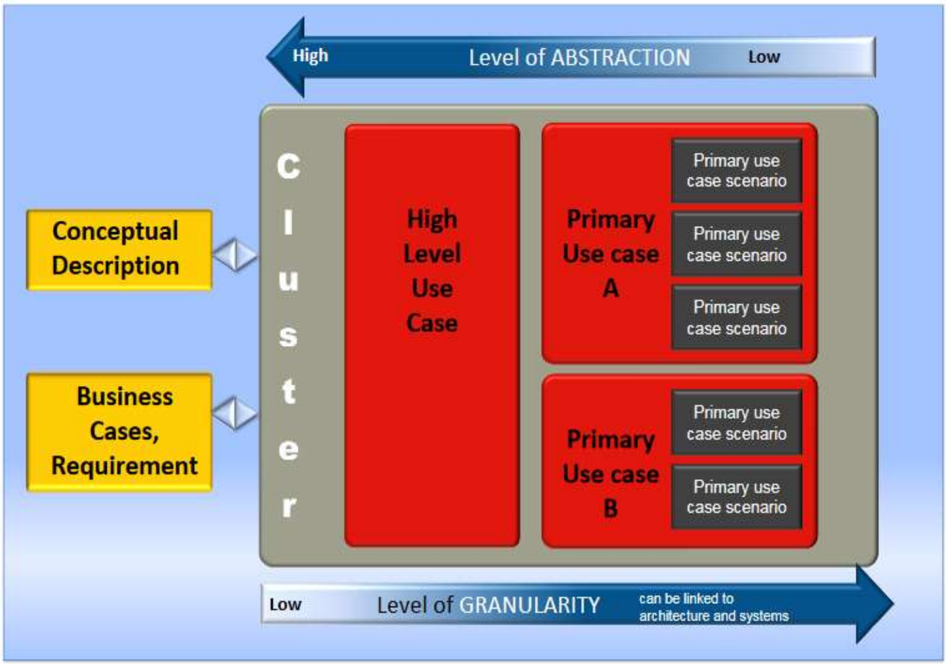

Figure 5: Use case structure based on Smart Metering Coordination Group [SGCG].

3.1.4 Project methodology of Use Cases

In FEVER project, a standardized methodology is followed for the description of the novel functionalities that will be developed in the project. Specifically, the adopted methodology is based on the UC terminology and classification analysis presented previously and the methodology defined by the international standard IEC 62559-2 [UCTM] for the UC methodology.

The use cases are divided into two general categories:

- **Business Use Cases (BUC):** Describe business processes that the actors of a given system must or may execute. These processes are derived from roles which have been previously identified and analyzed; there is no technical view. In this report the business use cases are described only conceptually.
- **Technical Use Cases**, are further subdivided to:
  - **Concepts (or High-Level Use Cases, HLUC)**: Describe the general idea of a function together with generic actors.
  - **Device/system use cases (or Primary Use Cases, PUC)**: A use case implemented in a specific system characterized by a defined boundary (i.e. it can be mapped on a defined architecture).

A key step for the UC definition is the identification and documentation of the different actors and their interactions. The actors are classified in two categories:

- **Business**: A business actor represents a party that participates in a business transaction. Within a given business transaction an actor performs tasks having adopted a specific role or a set of roles.
- **Technical**: An entity, (could be for example a system, or a device, etc.) that communicates and interacts with the system under design causing it to respond to events.

The use cases definition process comprises the following steps and it is illustrated in Figure 6:

1. With regards to the particular scope of FEVER, a preliminary phase consists of analyzing the flexibility needs from the DSO perspective in order to tackle the network operational and planning challenges towards energy transition. This analysis has been performed extensively in Section 2 of this document. In parallel, a questionnaire was prepared and distributed to project pilots in order to identify their individual business objectives.

2. In respect to the analysis of Step 1, the business goals of the main actors are identified considering their direct financial/business interest to achieve a certain objective. The business goals are also in line with the FEVER pilot needs and expectation within the project.
3. For each business goal, a BUC is defined describing the business processes towards the realization of the business goal.
4. For each BUC, the relevant HLUCs (technical) are defined describing conceptually the realization of the BUC.
5. The HLUCs are further detailed in a more extended and complete description, providing a high-level overview of the interactions among various actors and the preconditions. A specific description template was used for this purpose, available at Annex A
6. The development of a narrative for each of the HLUCs permits to identify relevant PUCs which are further analyzed with a short description that considers the main actors involved and specifies functions taking place.
7. Checking the use cases specifications and list of actors. If there are inconsistences or the description is not comprehensive, the process is repeated, starting again from Step 4.

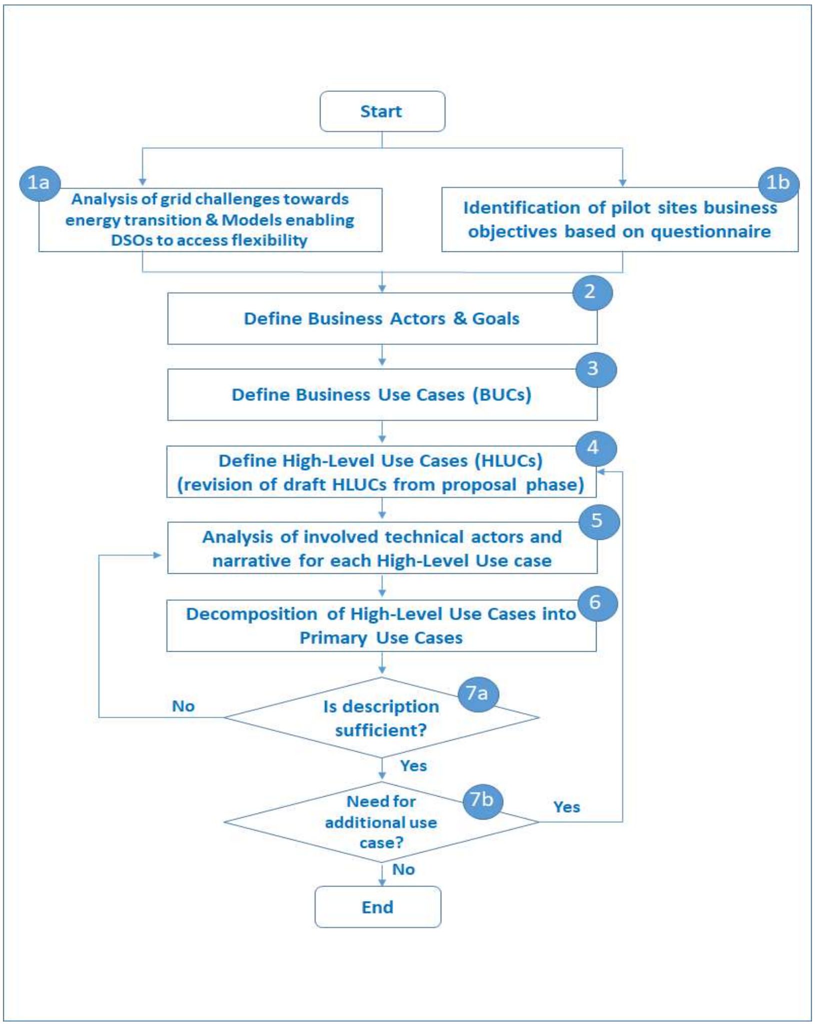

Figure 6: Flow chart of use case analysis process

3.2 Use Case Actors

The scope of this section is to establish a common terminology for the description and analysis of the business and technical use cases. The following tables provide a general definition of the actors involved in the use cases.

3.2.1 Business Actors

Table 3 provides the list of actors involved in FEVER as well as a generic description of their responsibilities. The relationships and interactions among the FEVER actors are illustrated in Figure 7. The definition of the FEVER Role Model is realized in respect to the Harmonized European Electricity Market Role Model[3] (HEEMRM).

Table 3: List of business actors

Actor Name	Acronym	Actor Type	Description
Balance Responsible Party	**BRP**	Role from Harmonized European Electricity Market Role Model	A party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Scheduling Area entitling the party to operate in the market. This is the only role allowing a party to nominate energy on a wholesale level. The meaning of the word “balance” in this context signifies that the quantity contracted to provide or to consume must be equal to the quantity really provided or consumed.
Energy Community Member	**ECM**	Actor	Member of an Energy Community
Balancing Service Provider	**BSP**	Role from Harmonized European Electricity Market Role Model	A party with reserve-providing units or reserve-providing groups able to provide balancing services to one or more Load-Frequency Control (LFC) Operators
Consumer	**Con**	Role from Harmonized European Electricity Market Role Model	A party that consumes electricity. This is a Type of Party Connected to the Grid
Distribution System Operator	**DSO**	Actor	Entity responsible for: distribution network planning and development; safe & secure network operation; data management associated with the utilization of the distribution grid; procurement of flexibility services
Energy Community Market Operator	**ECMO**	Actor	A party that provides a service whereby the offers to sell electricity are matched with bids to buy electricity within an Energy Community
Energy Community Responsible	**ECR**	Actor	A party responsible for representing Energy Community in the market negotiations
Generic Market Operator	**GMO**	Role	Generalization of Market Operator overarching the role of Market Operator at different electricity grid domains (generation, transmission, distribution, sub-distribution). It is a party that provides a service whereby the offers to sell electricity are matched with bids to buy electricity. This usually is an energy/power exchange or platform.
Flexibility Aggregator	**FA**	Role	A party that aggregates flexibility offered by a Flexibility Service Provider. It offers flexibility aggregation and management services to Flexibility Service Providers.

[3] https://www.entsoe.eu/digital/cim/role-models/

Flexibility Service Provider	**FSP**	Role	A party providing flexibility services to energy stakeholders via bilateral agreements or flexibility markets
Flexible Prosumer	**FP**	Role	A prosumer that owns and manages dispatchable DER generation/ consumption/ storage asset(s)
Local Market Operator	**LMO**	Role	Specialization of the GMO within the sub-distribution domain (i.e. microgrid, Energy Community)
Market Operator	**MO**	Role from Harmonized European Electricity Market Role Model	A Market Operator is a party that provides a service whereby the offers to sell electricity are matched with bids to buy electricity. This usually is an energy/power exchange or platform.
Microgrid Market Operator	**MgMO**	Actor	Specialization of the GMO within the microgrid context
Microgrid Member	**MgM**	Actor	Member of a microgrid
Microgrid Responsible	**MgR**	Actor	An entity responsible for the monitoring and management of a microgrid as well as for representing microgrid members in the market negotiations
Party Connected to the Grid	**PCG**	Role from Harmonized European Electricity Market Role Model	A party that contracts for the right to consume or produce electricity at an Accounting Point.
Producer	**Pr**	Role from Harmonized European Electricity Market Role Model	A party that produces electricity. This is a type of Party Connected to the Grid.
Regional Market Operator	**RMO**	Role	Specialization of the GMO at regional level of distribution network
Sub- Distribution System Operator	**Sub-DSO**	Actor	A party responsible for the operation of an area of the LV distribution grid
System Operator	**SO**	Role from Harmonized European Electricity Market Role Model	System Operator means a natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the system in a given area and, where applicable, its interconnections with other systems, and for ensuring the long-term ability of the system to meet reasonable demands for the distribution or transmission of electricity.
Transmission System Operator	**TSO**	Actor	Entity responsible for providing and operating high and extra-high voltage networks for long-distance transmission of electricity as well as for supply of lower-level regional distribution systems and directly connected customers

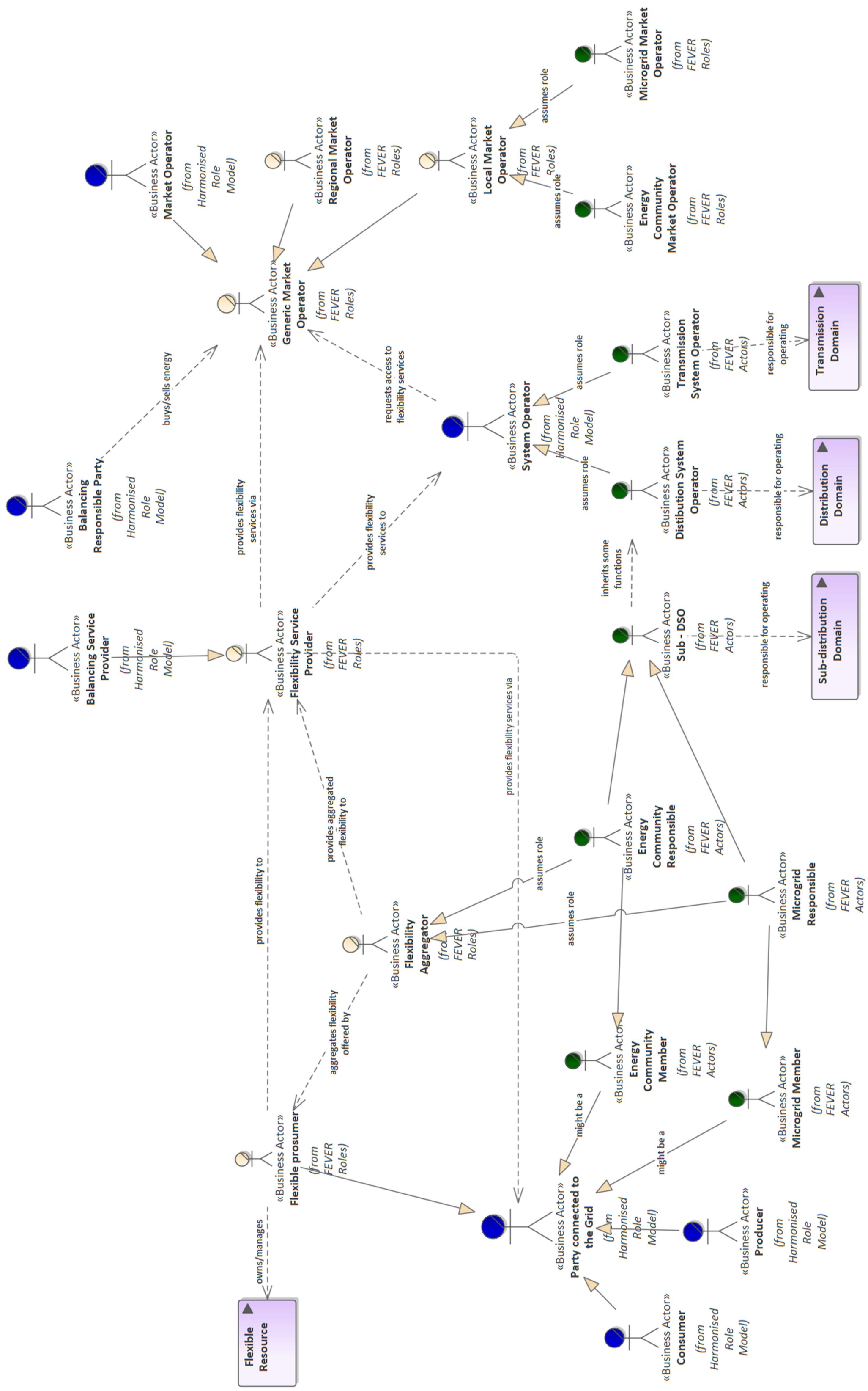

Figure 7 FEVER Role Model

3.2.2 Logical Actors

Table 4 provides a generic description of the logical actors, i.e. systems, applications, devices, etc. involved in the project.

Table 4: List of logical actors

Actor Name	Acronym	Actor Type	Description	Notes
Advanced Metering Infrastructure	AMI	System	The system composed of all the devices, applications and data bases that permits to measure, remotely collect and manage data from smart meters.	Commercial product
Bidding Application	BA	Application	Application defining the optimal bidding strategy for the wholesale and balancing market participation of BRPs and BSPs	Will not be developed in the project
Critical Event Forecaster	CEF	Application	Application, in charge of predicting possible congestion or over-under voltage events in the succeeding H-time (forecasting horizon). It is included in the DSO Toolbox	Will be developed in the project by UdG
Critical Event Prevention Application	CEPA	Application	Application, in charge of predicting possible congestion or over-under voltage events in the succeeding H-time (forecasting horizon). It is included in the DSO Toolbox.	Will be developed in the project by ICOM/UdG
Day-Ahead Market Schedule Disaggregation Application	DAMSDA	Application	Application responsible for the disaggregation of a market schedule at nodal/area level of the distribution system	Will be developed in the project by HEnEx
Day-Ahead Market Scheduler	DAMSc	Application	Application that implements a day-ahead market which is a mandatory pool or power exchange where the market model clears buy and sell orders using marginal pricing	Will be developed in the project by HEnEx
Distributed Energy Resource	DER	Device	Any device, load, battery, generation asset that can change its consumption / injection of electricity upon request of the aggregator/prosumer, providing flexibility to the system	Commercial product
Distribution Management System	DMS	System	A system utilized by the DSO which provides the functionalities for advanced monitoring and controlling of the distribution grid from a centralized location,	Commercial product

			typically the control centre.	
DSO Toolbox	DSO Toolbox	System	A suite of gird-oriented tools complementing DSO's legacy systems enabling more advanced observability and management of the distribution grid.	Will be developed in the project by ICOM/UdG/UPC
Energy Forecaster	EF	Application	A forecasting application in charge of predicting demand and generation values for specific points of the grid in the succeeding H-time. It facilitates aggregated values of individual consumptions/productions and weather forecast data.	Will be developed in the project by UCY/UdG
Energy Management System	EMS	System	The system responsible for monitoring and controlling DER assets. EMS extracts the potential flexibility from DER assets with regards to their operational status and constraints. Different types of EMS are considered in the project: Factory Energy Management System (FEMS) controls factories and commercial buildings; Home Energy Management System (HEMS) controls residential locations; a Charging Energy Management System (CEMS) controls electric vehicle charging stations, etc.	Commercial and custom made by INEA
Flexibility Management System	FMS	System	The system operated by the flexibility aggregator to aggregate / disaggregate flexibilities for trading purposes	Will be developed in the project by FLEX/ INEA/ AAU
Flexibility Service Consuming Agent	FSCA	Application	The agent responsible for transforming the flexibility needs of an actor to a bidding strategy in respect to the requirements imposed by the flexibility markets or the bilateral agreements	Will be developed in the project by INEA/ AAU/ FLEX
Flexibility Service Providing Agent	FSPA	Application	The agent responsible for transforming the available flexibility of an actor to a bidding strategy in respect to the requirements imposed by the flexibility markets or the bilateral agreements	Will be developed in the project by INEA / AAU/ FLEX

Flexibility Trading Platform	FTP	System	The system responsible for the trading of flexibility among different stakeholders	Will be developed in the project by INEA
Geographic Information System	GIS	System	System that manages all the static information related to the grid assets and location	Commercial product
Grid Operation Planner	GOP	Application	Service in charge of planning the grid operation satisfying a predefined objective function that depends on the specific scenario. It determines the need of reconfiguration or flexibility. It is included in the DSO Toolbox.	Will be developed in the project by UdG
Intra-day Flexibility Trading Mechanism	IDFTM	Application	Application that will implement the intra-day continuous trading mechanism	Will be developed in the project by HEnEx
Island Power Management Application	IPMA	Application	Application included in the DSO Toolbox which is responsible to define a mitigation strategy in case of uncontrolled island situation. In addition, it is able to communicate/command with the SCADA system and PEDs.	Will be developed in the project by UPC/ICOM
Loss Reduction Application	LRA	Application	Application responsible for extracting the flexibility needs which will enable the flattening of the network demand curve measured at substation level and will result in the minimization of the network technical losses. It is included in the DSO Toolbox	Will be developed in the project by UdG/ICOM
Microgrid Flexibility Management System	MgFMS	System	System responsible for managing the microgrid operation and offering flexibility services to energy stakeholders via bilateral contracts or flexibility markets	Will be developed in the project by UCY/INEA
Network Data Processing Application	NDPA	Application	The application responsible for pre-processing the source network data (transmission and distribution grid) before being integrated in the DAMSc	Will be developed in the project by HEnEx
Peer-to-peer flexibility trading platform	P2P-FTP	System	System comprising the business and market processes related to p2p business trading	Will be developed in the project by IBM
Power Electronic Device	PED	Device	It is a power electronic device used to exchange power with batteries/EVs,	Will be developed in the project by

			and also PV system, which is also able to communicate with the SCADA/IPMA/PQS, measure grid and islanding status, and also can be commanded by SCADA/IPMA/PQS.	UPC
Power Flow Simulator	PFS	Application	An application that simulates power flows in the grid, predicting the voltage and current values of each bus for the following H-time. The calculation is based on the existence of a vector of measurements or predictions, related to demand and generation, for the same H-time.	Commercial or open source product
Power Quality Service	PQS	Application	Application that calculates set-points for devices to mitigate power quality issues. It is included in the DSO Toolbox	Will be developed in the project by UPC
Real-Time Balancing Market Mechanism	RTBMM	Application	It is a balancing and congestion management application for computing real-time balancing actions and Distributed Locational Marginal Prices (DLMP) for retail markets.	Will be developed in the project by UCL
Remuneration Mechanism	RM	Application	The mechanism defining the financial compensation for purchasing flexibility services	Will be developed by SWW/ SWH/ INEA
Self-Healing Application	SHA	Application	Application responsible for mitigating faults in distribution grid considering grid and DER flexibilities. It is included in the DSO Toolbox	Will be developed in the project by UdG/ICOM
Supervisory Control And Data Acquisition	SCADA	System	A system in charge of overall monitoring and control of the distribution and transmission grid. It integrates communication, remote monitoring and control, signal processing and logic, and data storage functionalities. It includes a user interface called control center room.	Commercial product
Switchgear	SG	Device	Actuators of the LV grid that permit to switch lines and change grid configuration.	Commercial product

Switchgear Dispatch Scheduler	SDS	Application	Application responsible for dispatching the grid reconfiguration schedule extracted by other applications of the DSO Toolbox. It is included in the DSO toolbox	Will be developed in the project by EST/ICOM
Voltage Compensation Application	VCA	Application	Application responsible for monitoring and mitigating voltage excursions via reactive power procurement. It is included in the DSO Toolbox	Will be developed in the project by UdG/ICOM
Weather Forecaster	WF	Application	Application out of FEVER project offering weather forecast services.	External service

3.3 Business use cases

This section presents the FEVER business use cases as these were identified from the completed use case description templates for the demonstration sites. The targeted domains identified in respect to the project scope, as it is illustrated in Figure 8, are: the DSO-domain, the Market Operator-domain and the Flexibility Service Provider-domain. In the following paragraphs, the FEVER business use cases are presented in more detail.

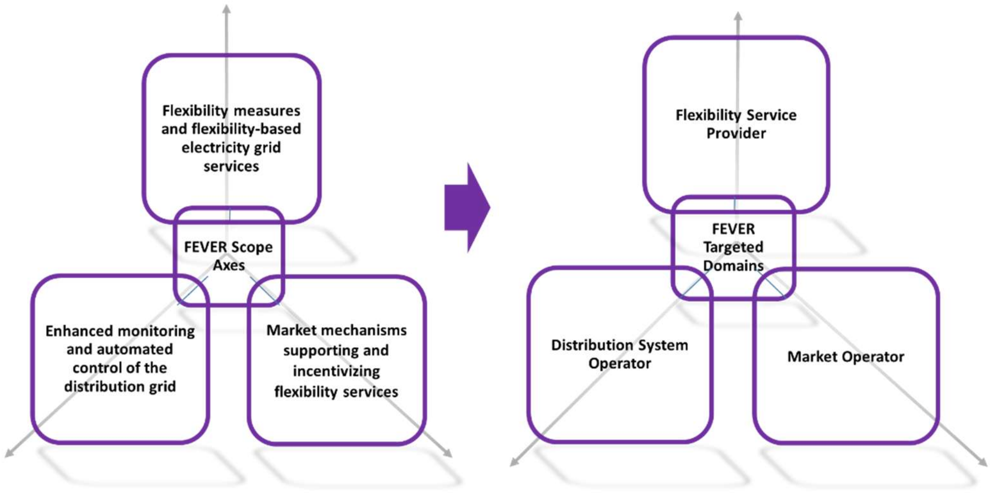

Figure 8: FEVER targeted business domains

3.3.1 Business use cases from DSO's perspective

DSOs are responsible for operating, maintaining and developing the distribution network in the most cost-efficient way in order to ensure the required network capacity for serving the consumption. Maintaining the secure and reliable network operation may require the reinforcement and extension of distribution networks which is not always the most efficient and cost viable solution. The exploitation of DER flexibility by DSOs to complement grid reinforcement towards grid operational support is the main objective.

The exploitation of the DER flexibility by the DSOs can be realized based on bilateral contracts with Flexibility Service Providers / Flexibility Aggregators and/or via flexibility markets. In the former case, the DSO requests flexibility services from Flexibility Service Providers / Flexibility Aggregators who are a-priori selected and contracted to support network operation in the most technically and economically efficient way. Alternatively, the DSO procures flexibility as market product from (local) flexibility markets. Both alternatives will be examined in this project.

Three business use cases were identified in order to fulfill DSO's business goals, as listed below:

- **BUC 01: Exploit flexibility for preventing network operational issues** aiming to minimize/delay network reinforcement costs. The respective HLUCs realizing this business goal are:
  - **HLUC 01:** Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc.)
  - **HLUC 02:** Leveraging the batteries' inverters towards reactive power ancillary services
  - **HLUC 08:** Economically optimized flexibility leveraging for a grid-connected microgrid
  - **HLUC12:** Creating dynamic tariffs based on flexibility use in the actual regulatory framework
- **BUC 02: Advanced network management under critical conditions** aiming to increase network security and resilience. The respective HLUCs realizing this business goal are:
  - **HLUC 03:** Leveraging the flexibility of the storage assets for real time detection of uncontrolled islanding
  - **HLUC 04:** Self-healing operation after critical event considering DER & grid flexibility
  - **HLUC 05:** Flexibility exploitation for islanded microgrid operation
- **BUC 03: Reduce technical losses utilizing DER flexibility and power electronics** aiming to

enhance network operational efficiency & quality of supply. The respective HLUCs realizing this business goal are:
- **HLUC 06:** Leveraging DER flexibility towards enhancing network operational efficiency
- **HLUC 07:** Improving power quality and reducing losses through power electronics

The realization of each business use case fulfills specific business goals not only for the System Operators (network-oriented ones) but also for all the relevant stakeholders, as these are presented in Table 5.

Table 5: DSO perspective: main objectives of key business actors of interest in FEVER

Actor	Main Objectives
Distribution System Operator	Minimize/delay network reinforcement costs Increase network security and resilience Enhance network operational efficiency & quality of supply
FEVER Market Operator	Develop the market framework and mechanisms enabling active & reactive power flexibility trading for grid support
Flexibility Aggregator	Offering aggregation management services to Flexibility Service Providers
Flexibility Service Provider	Revenues from offering flexibility services to energy stakeholders
Flexible Prosumer	Optimize flexible resource management and maximize profits

Each business use case requires the invocation of one or more high level (technical) use cases which outline the conceptual description of the realization of the business objective as it is illustrated in Figure 9.

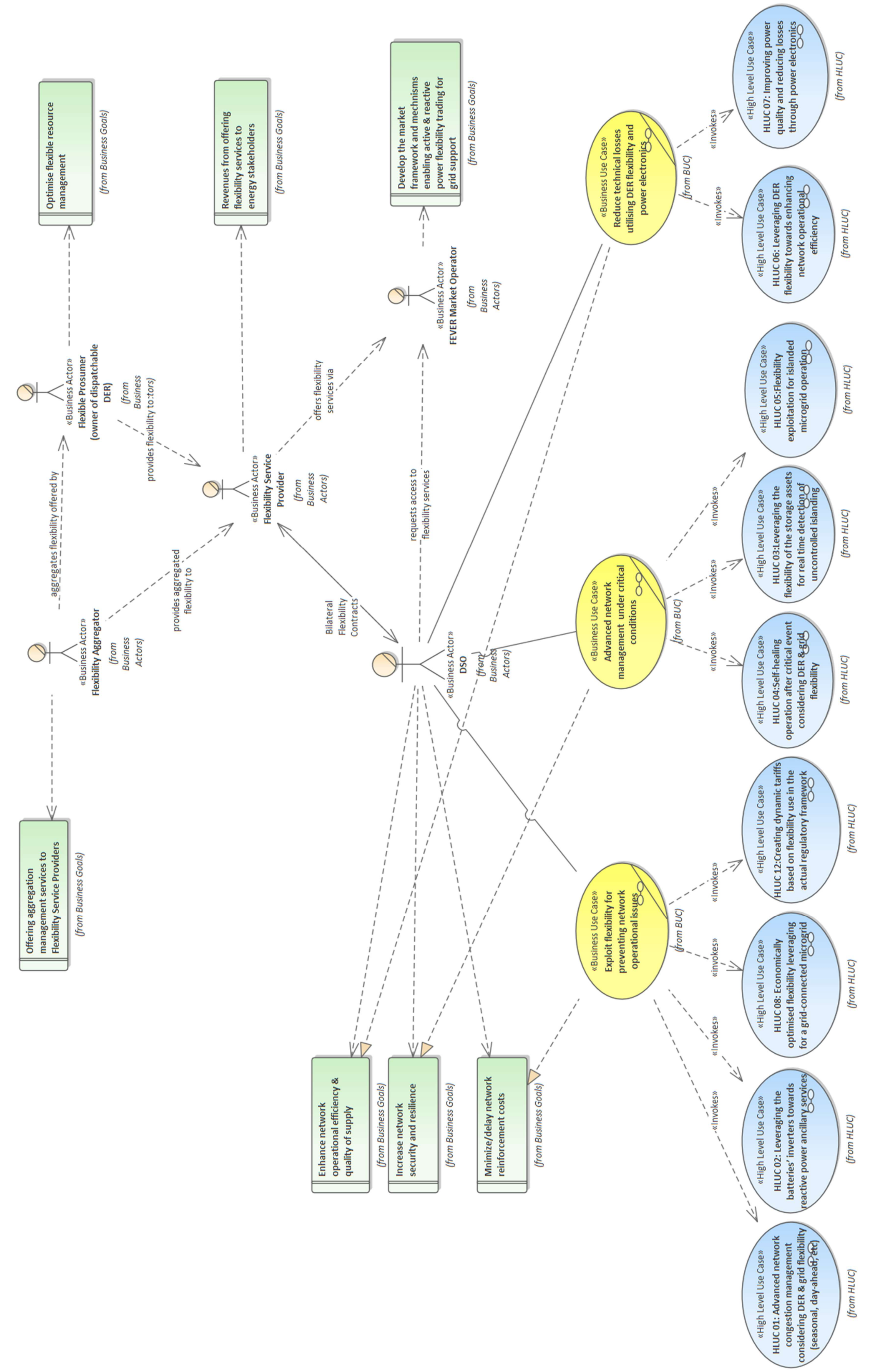

Figure 9: Market-based procurement of DER flexibility

3.3.2 Business use cases from the Market Operator perspective

The goal of the Generic Market Operator is to facilitate flexibility trading in different market timeframes, i.e. day-ahead, intra-day and real-time. New market mechanisms should be introduced or existing ones should be enhanced in order to exploit flexibility from both transmission and distribution system. This overarching principle of the Market Operators is to support a level playing field for all kinds of flexible resources.

In this respect two business goals were identified for the market operation: i) integrating DER flexibility located at both transmission and distribution level into wholesale (day-ahead) and balancing (i.e. real-time) electricity markets and ii) facilitating DER flexibility trading at distribution level.

- **BUC 04: Facilitate integration of DER flexibility into wholesale and balancing markets** by introducing new market mechanisms that facilitate DER flexibility exploitation in day-ahead and real-time balancing markets. The respective HLUCs realizing this business goal are:
  - **HLUC 09:** Day-ahead market mechanisms incentivizing energy flexibility trading for mitigating problems of the transmission system & distribution network, integrating wholesale and retail markets
  - **HLUC 11**: Real-time market mechanism incentivizing energy & capacity flexibility trading from FSPs, to address balancing and T&D congestion management, integrating wholesale and retail markets
- **BUC 05: Facilitate integration of DER flexibility into flexibility markets at distribution level** aiming to introduce new market mechanisms facilitating DER flexibility exploitation located at distribution level considering intra-day and close to real-time timeframes. The respective HLUCs realizing this business goal are:
  - **HLUC 10:** Intra-day market mechanisms incentivizing active & reactive energy flexibility trading for mitigating problems of the distribution network
  - **HLUC 13**: Improving the outcome in flexibility by introducing sector coupling
  - **HLUC 14**: Form a first example of a regional flexibility exchange model

The realization of the flexibility market solution serves specific business goals not only for the Market Operators but also for all the relevant stakeholders, as these are presented in Table 6.

Table 6: Market Operator perspective: main objectives of key business actors of interest in FEVER

Actor	Main Objectives
Market Operator	Introduce new market mechanisms facilitating DER flexibility integration in distribution grid
System Operators (DSO/TSO)	Ensure the reliable and secure network operation
Flexibility Aggregator	Offering aggregation management services to Flexibility Service Providers
Flexibility Service Provider	Revenues from offering flexibility services to energy stakeholders
Flexible Prosumer	Optimize flexible resource management and maximize profits
Balance Responsible Party	Offer more competitive contracts to retail market considering LMPs and exploit DER flexibility for balancing purposes within balancing group and at trans-regional level

The business use cases require the invocation of five high level (technical) use cases which outline the conceptual description of the realization of the business objective as it is illustrated in Figure 10.

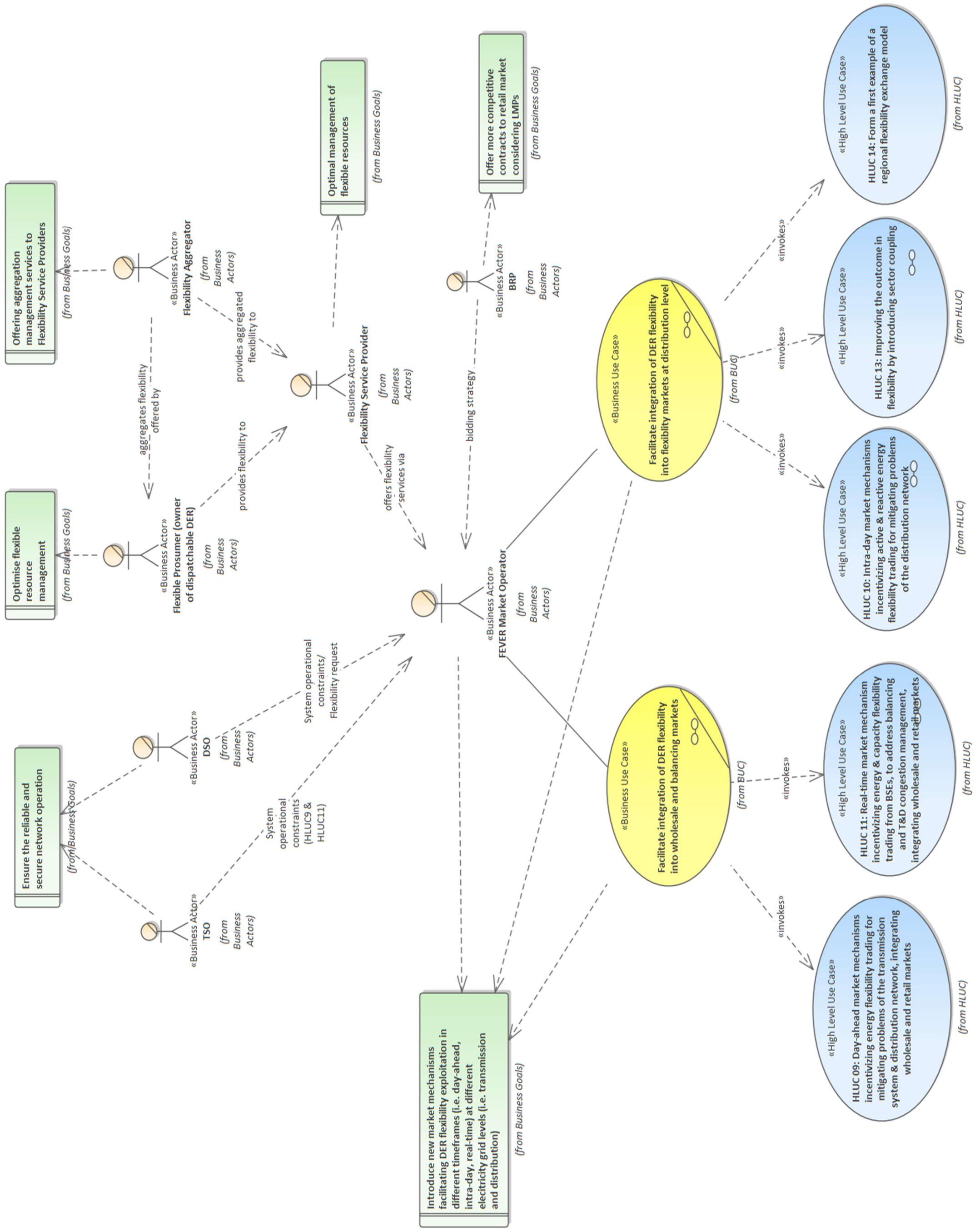

Figure 10: Integrating DER flexibility into electricity markets considering different timeframes

3.3.3 Business use cases for energy communities – p2p flexibility trading

Energy community can be considered as an ecosystem of (flexible) prosumers organized at local or regional level. While energy communities can exist on multiple levels, the project focuses on prosumer-centric communities.

In contrast to maximizing its profit, the energy communities under consideration shall provide environmental, economic or social community benefits for their members or the local area. In that respect they are similar to the Citizen Energy Communities or Renewable Energy Communities as described in Art. 16 of the EC Directive on the Internal Market for Electricity Directive on “Citizen Energy Communities” (EMD) or Art. 22 of the EC Directive on the promotion of the use of energy from renewable sources on “Renewable Energy Communities” (RED) respectively.

While such a community implies a high level of “self-consumption” or “self-supply” inside the community, it strives for an overall system optimum with comprehensive energy supply and consumption orientation, targeting inclusion of all energy vectors. Governance policies and incentive mechanisms like special tariffs or pseudo-currencies will be explored.

The respective high-level use case realizing the energy community's objectives is the:

- **HLUC 15: P2P flexibility trading.**

3.4 Technical use cases

This section presents and analyses the FEVER technical use cases which can be further decomposed, in respect to Section 3.1.4, to:

- **High Level Use Case (HLUC)** aiming to define the device/system boundaries and interactions between the system(s) and external actors to fulfil a goal for the actor(s). Furthermore, from a more technical point of view a device/system UC can take the form of [SGCG]:
- **Primary Use Case** defines the tool(s) for reaching one (or many) goal that are described by High-Level UCs.
- **Secondary Use Case** describes the core functionalities that are used by multiple PUCs.

More specifically, the description of the HLUCs comprises:

- **Scope** *presents the main subject each HLUC deals with and defines its boundaries/limits*
- **Objectives** *identifies the business goal(s) to be served with respect to business analysis in Section 0*
- **Actors** *identifies the list of logical actors (with respect to Section 3.2) involved to realize each use case*
- **Short Narrative** *provides an overview of the key concept of the use case outlining the main functionalities of each use case*
- **Complete Narrative** *details the functionalities and actor interactions of each use case describing what occurs when, why, with what expectation, and under what conditions*
- **PUCs** *the relative subset of FEVER functionalities realizing each HLUC*
- **Preconditions and Assumptions** *identifies the general assumptions about systems' configurations and state of actors/activities prior to the use case's initiation.*
- **Use case diagram** *refers to the UML diagram elaborating the understanding of the HLUC by illustrating the correlation among actors and functionalities*

3.4.1 High Level Use Cases

3.4.1.1 HLUC 01: Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc.)

Scope

The scope of this use case is to describe the processes and tools which enable DSOs to identify network overloading issues from planning down to operational time-frame based on forecasted and real network operational data and to setup the remedial mechanisms for maintaining the secure and reliable network operation. Two remedial mechanisms are considered in this use case: grid reconfiguration by properly modifying the network switchgears; and, the procurement of DER active energy flexibility offered by Flexibility Service Providers via either bilateral contacts or flexibility markets.

Objectives

The objective of this use case is to prevent network congestion issues at distribution level and consequently minimize/delay network reinforcement costs by combining DSO's conventional network remedial mechanisms with DER flexibility remuneration whenever this is technically and economically viable.

Actors

DSO Toolbox - Critical Event Prevention Application (CEPA), Distribution Management System (DMS), Weather Forecaster (WF), Flexibility Service Providing Agent (FSPA), Flexibility Service Consuming Agent

(FSCA), Flexibility Trading Platform (FTP), Flexibility Management System (FMS), Switchgear Dispatch Scheduler (SDS), switchgear, Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Energy Management System (EMS)

Short Narrative

This use case has the objective of preventing congestion issues in the distribution grid by exploiting network flexibility, i.e. reconfiguration of the network topology in the problematic grid area, and DER flexibility, provided by dispatchable DERs located at distribution level. Congestion management can be considered in different timeframes, i.e. real-time operation, operational planning, and long-term planning. DER flexibility remuneration can be realized via bilateral contracts and/or flexibility markets operated by a third party.

Complete Narrative

Congestion management can be considered in different timeframes from planning down to operational one:

- Seasonal planning: to avoid congestion issues deriving from a significant demand variation due to the change of people’s habits in the different seasons (e.g. a vacations village that gets full of tourists only some months per year)
- Day-ahead planning: periodic daily forecasting of consumption/generation (using smart meter data) to foresee possible grid issues during the following day and prevent them by planning the operation of the grid.
- Close-to real time planning: monitoring of the saturation levels of grid equipment through DSO real time monitoring system, and consequent planning of preventing action, if the levels are close to the maximum limit.

The Critical Event Prevention Application (CEPA), which is a component of the DSO Toolbox to be developed within the framework of the project, is responsible for identifying network overloading events through direct real time monitoring of grid data from DSO’s legacy systems and/or by performing power flow analysis of the network operation considering real time data from DSO’s legacy systems, forecasted generation and consumption profiles, in respect to the congestion management horizon and the weather forecast data provided by an external weather forecasting agency, and the technical constraints of the network infrastructures. In case that a network overloading event is identified, the CEPA plans the mitigation plan for relieving the congested network area by considering primarily grid reconfiguration and DER flexibility procurement as supplementary action if required.

Grid reconfiguration entails the proper scheduling of the switchgear’s operational status in order to modify the network power flows such that the loading of the problematic area is limited. The dispatch of the grid reconfiguration schedule is facilitated by the Switchgear Dispatch Scheduler (SDS) which is responsible for ordering and assessing the switchgear status modification through the SCADA system (DS- SCADA) and at the time established in the schedule.

In case that mere grid reconfiguration is not adequate to mitigate the congestion issue, the flexibility offered by the distributed dispatchable consumption/production/storage units affecting the operation of the problematic area is exploited. The flexibility needs in terms of active power and spatial details are extracted by the analysis performed by the CEPA and are communicated to the Flexibility Service Providers either directly (bilateral contracts) or via a local flexibility market operated by an independent Market Operator. This interaction is realized by the Flexibility Service Consuming Agent (FSCA) adhering to the communication principles and specifications imposed by the flexibility markets or bilateral agreements.

The flexibility needs of the DSO are matched with the flexibility bids offered by the Flexibility Service Providers via an auctioning mechanism (Flexibility Trading Platform - FTP). The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO, including also the spatial-temporal requirements, are considered.

The extraction and trading of the flexibility capacities from distributed, dispatchable energy resources are managed by the local Energy Management System (xEMS) and the local Flexibility Service Providing Agent (FSPA). The extracted DER flexibilities are managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS).

After the grid reconfiguration dispatch and the activation of the requested flexibility by EMS at DER level, the effectiveness of the remedial actions is assessed by the Ex-Post Assessment Application (EPAA) based on real data from the DS-SCADA which is monitored periodically. The real monitoring data is the input for the power flow analysis performed by the Power Flow Simulator (PFS) which outputs the calculated network operational snapshot in terms of voltages and currents. The PFS outcome is processed by the Critical Event Forecaster (CEF) by comparing the network infrastructure loading with the thermal limits.

Preconditions and Assumptions

- **Bilateral contracts** are adequately defined so as to contain all the details (i.e. flexibility capacity, spatial indication of DERs relevant to electricity grid, etc.) for activating the flexibility in every situation requested by the DSO.
- **Spatial component of flexibility**: The flexibility offered by DER assets and the one requested by DSOs should be correlated with their location in the distribution grid since congestion issues have local and not systemic characteristics.
- **Availability and quality of data**: The network and consumption data requested by the CEPA for performing power flow analysis of the distribution grid should be available. Depending on the quality of data (granularity, updating interval, etc.) and the accuracy/resolution of the resulting generation and demand forecast will variate. Consequently, the performance of the CEPA application will be affected.

Use case diagram

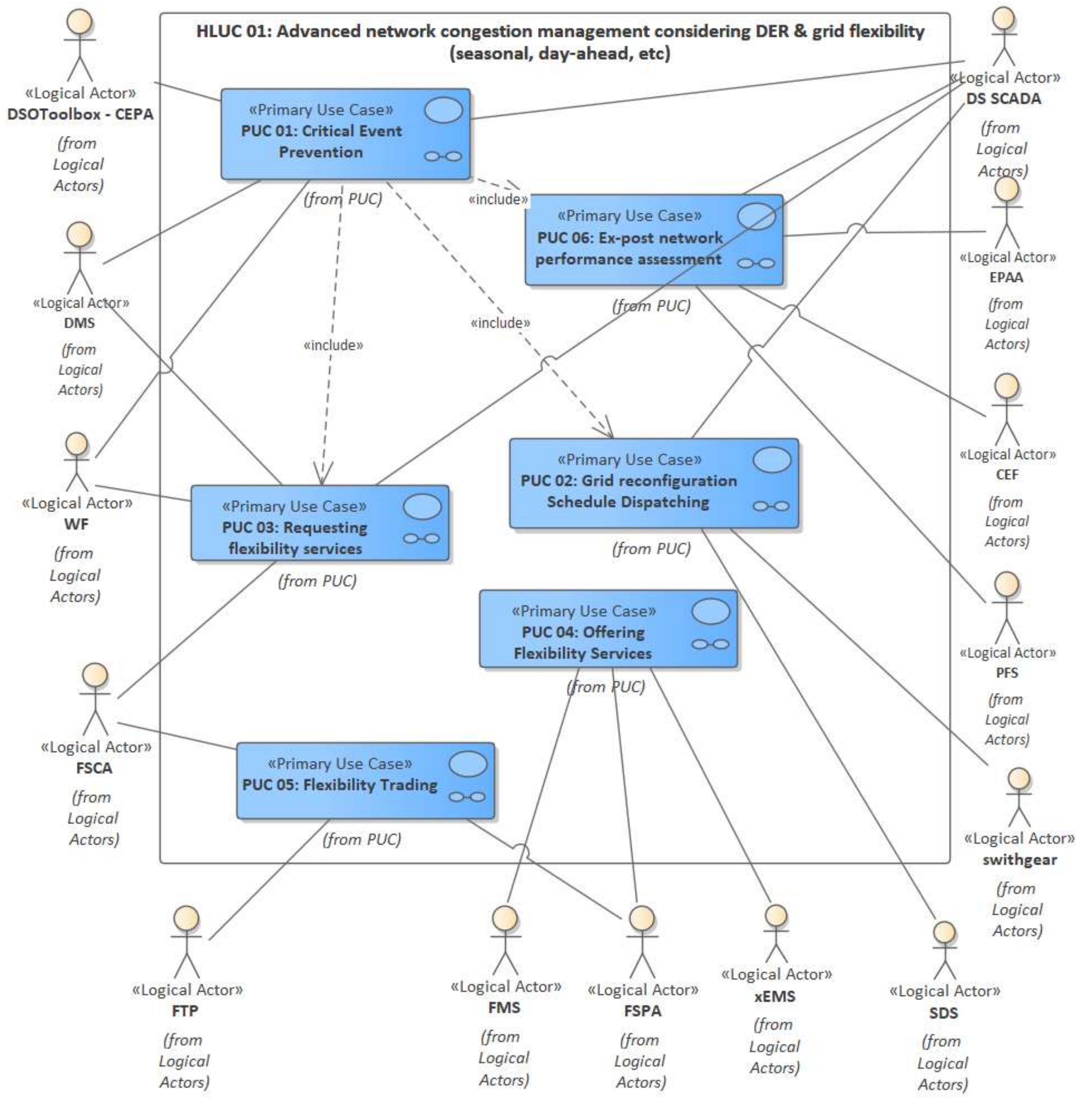

Figure 11: Use case diagram of HLUC 01

3.4.1.2 HLUC 02: Voltage compensation via reactive power procurement

Scope

The grid voltage level undergoes momentary variations, due to sudden changes of consumption and generation, especially in area of high distribution generation capacity installed. The scope of this use case is to describe i) the processes and tools which enables DSOs to identify voltage excursions from planning down to operational time-frame based on forecasted and real network operational data and ii) the mitigation mechanisms for voltage compensation. The voltage compensation is realized by the exploitation of reactive energy flexibility offered by distributed storage units associated with the problematic grid area.

Objectives

The objective of this use case is to prevent voltage issues at distribution level and consequently minimize/delay network reinforcement costs by exploiting reactive energy flexibility provided by distributed storage units.

Actors

DSO Toolbox – Voltage Compensation Application (VCA), Weather Forecaster (WF), Distribution Management System (DMS), Flexibility Service Providing Agent (FSPA), Flexibility Service Consuming Agent (FSCA), Flexibility Trading Platform (FTP), Flexibility Management System (FMS), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Energy Management System (EMS)

Short Narrative

This use case has the objective of preventing voltage excursions in the distribution grid by exploiting battery storage reactive power flexibility located at distribution level. Momentary voltage issues are identified and corrected in the close to-real-time frame. DER flexibility remuneration can be realized via bilateral contracts and/or flexibility markets operated by a third party.

Complete Narrative

The Voltage Compensation Application (VCA), which is a component of the DSO Toolbox to be developed within the framework of the project, is responsible for identifying voltage excursions by performing power flow analysis of the network operation considering the real grid monitoring data from DSO's legacy systems, and the voltage constraints defined by the Network Codes. In case that a voltage excursion (i.e. over/under-voltage) is identified, the VCA defines the reactive energy flexibility needs in terms of energy, time and location.

To make a suitable use of reactive power control capability it is necessary to have a higher observability of the network in order to detect and smooth voltage surges and drops. In this respect, the power electronics components of the battery array together with other monitoring devices and sensors can be used also for acquiring field data. Collection of data is done by the DSO, through its SCADA infrastructure (sensors, analyzers, PED, etc.). These data are centralized in the DSO Toolbox database and compared to the predefined voltage thresholds by the Critical Event Forecaster (CEF) in order to identify any voltage constraint violation.

Upon voltage excursion event, the flexibility needs in terms of reactive power and spatial details are extracted by the analysis performed by the VCA and are communicated to the Flexibility Service Providers either directly (bilateral contracts) or via a local flexibility market operated by an independent Market Operator. The Flexibility Service Consuming Agent of the DSO (FSCA) is responsible for realizing such interactions.

The flexibility needs of the DSO are matched with the flexibility bids offered by the Flexibility Service Providers via an auctioning mechanism (Flexibility Trading Platform - FTP). The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO, including also the spatial-temporal requirements, are considered.

The extraction and trading of the flexibility capacities from distributed, dispatchable energy resources are managed by the local Energy Management System (EMS) and the local Flexibility Service Providing Agent

(FSPA). The extracted DER flexibilities are managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS).

After the activation of the requested flexibility by EMS at DER level, the effectiveness of the remedial actions is assessed by the Ex-Post Assessment Application (EPAA) based on real voltage measurements from the DS-SCADA which is monitored periodically.

Preconditions and Assumptions

- **Spatial component of flexibility:** The flexibility offered by DER assets should be correlated with their location in the distribution grid since voltage issues have local and not systemic characteristics.
- **Availability of real time voltage data**: Close to real time measurements are required for analysis of the network voltage profile. In light of this, the Flexibility Service Providers should have storage assets equipped with PEDs enabling such functionalities.
- **Bilateral contracts** are adequately defined so as to contain all the details (i.e. flexibility capacity, spatial indication of DERs relevant to electricity grid, etc.) for activating the flexibility in every situation requested by the DSO. Access to real-time field measurements of the PEDs by the DSO should be included within the bilateral agreement.

Use case diagram

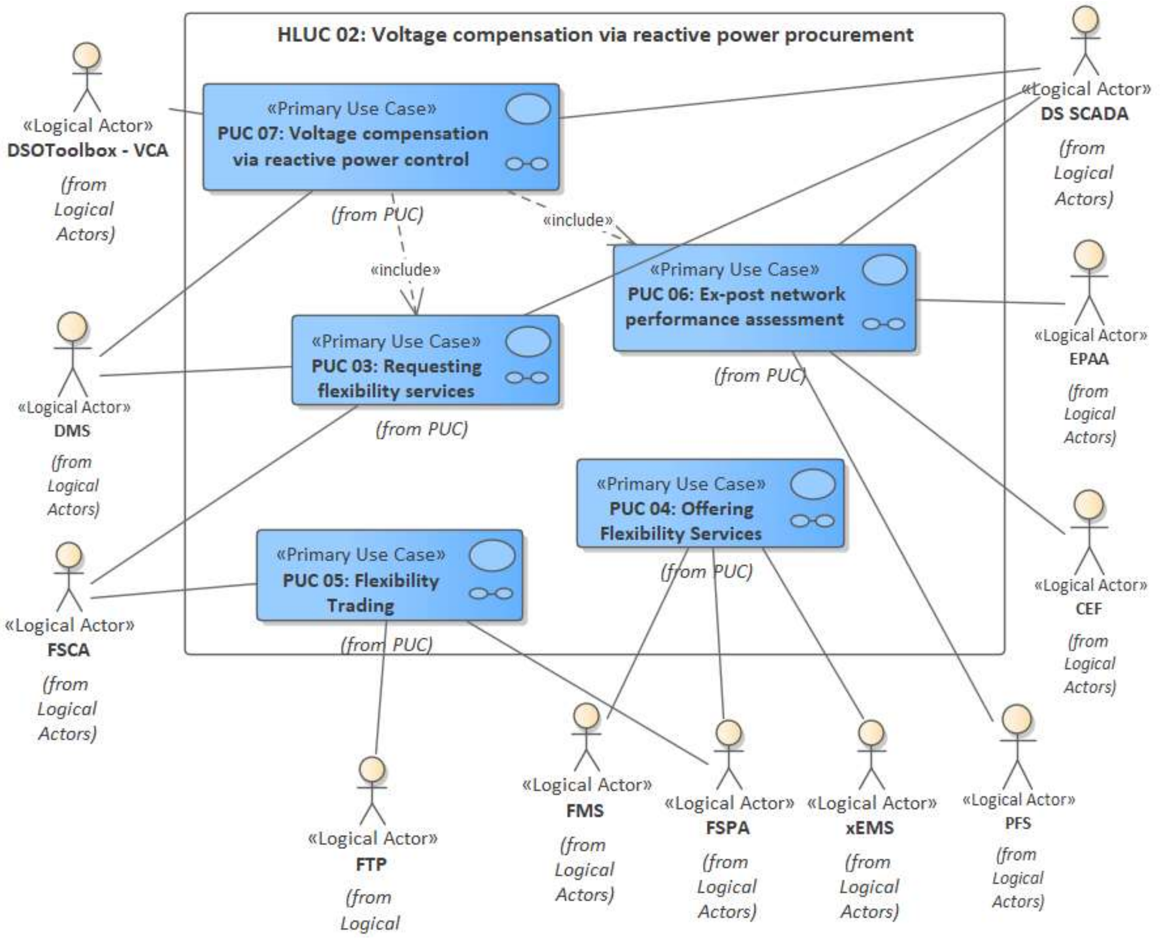

Figure 12: Use case diagram of HLUC 02

3.4.1.3 HLUC 03: Real time detection of uncontrolled islanding by leveraging storage flexibility

Scope

The high share of distributed renewable production and storage capacities in the distribution grid can significantly modify the power flows and this affects, consequently, the expected protection system performance under abnormal grid operational conditions, i.e. faults. In light of this, it might happen that, due to the equilibrium between local energy consumption and production, the protection system does not detect the island operation and the grid remains electrified in an uncontrolled way. This results in significant human safety risks. The scope of this use case is to develop the tools that will enable DSOs i) to detect uncontrolled islanding situations in real time by combining grid monitoring data from DSO's legacy systems and field measurements from DER assets and Power Electronic Devices (PEDs) and ii) to mitigate such situations rapidly to avoid human safety risks.

Objectives

The objective of this use case is to enable the real-time detection and mitigation of uncontrolled islanding based on grid, PEDs and DER asset monitoring data aiming to increase the security and resilience of the distribution grid.

Actors

DSO Toolbox – Island Power Management Application (IPMA), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Power Electronic Devices (PED), Distributed Energy Resource (DER)

Short Narrative

The detection and mitigation of uncontrolled islanding requires advanced monitoring and observability of the grid not only at substation or feeder level but real time monitoring at PED/DER asset level. In this respect, DSOs are capable of monitoring and assessing in real time the operational behavior of the network's and, if available, the DERs' protection system. In case of inconsistences under faulted grid conditions, a mitigation plan should be scheduled and implemented by sending set-points to the PED assets and trigger grid reconfiguration in order to avoid human safety risks. The Island Power Management Application (IPMA) of the DSO Toolbox, which will be developed within the framework of this project, is responsible for detecting and mitigating uncontrolled islanding situations.

Complete Narrative

The detection of uncontrolled islanding is conducted using a two-layer monitoring and observability of the grid: i) identification of the abnormal grid condition and ii) the detection of non-activation of the passive anti-islanding protection of the inverters of the DER assets within the problematic grid area. The IPMA is responsible for analyzing periodically and with high frequency the monitoring data for the grid operation from different sources i.e. network status from the DS-SCADA and the local grid operation from the PEDs. This comparative analysis performed by IPMA aims to identify the situation in which an island is created unintentionally, without the possibility to operate it, and the passive anti-islanding protections of DER inverters do not detect and interrupt the island. The island is not detected and interrupted by the passive anti-islanding protections of DER inverters if the grid parameters of the island stay within their non-detection zone (NDZ). The detection of an uncontrolled island is continuous and requires the implementation of advanced algorithms, e.g. graph theory, state estimation, etc. In case of a detected uncontrolled island, the IPMA proceeds with mitigation actions by introducing perturbations such as modifying production and/or consumption and/or altering grid configuration within the problematic area which is expected to have a cascading effect on the activation of the protection of the DER inverters.

The perturbations devised by the IPMA, i.e. modifications of the energy production/consumption of specific PED assets and grid configuration changes, are communicated by the DS-SCADA to grid assets (PED, circuit breakers). Due to exceptional and emergency conditions of this use case and the high safety risk associated, DSO is considered to have established predefined strategic bilateral agreements with PED/DER owners concerning the monitoring and control capabilities (the latter under emergency grid conditions exclusively) of PED/DER assets.

Preconditions and Assumptions

- **Availability of real time data at PED/DER level**: Close to real time measurements are required for the analysis of the network operation. In light of this, PEDs must have been installed and be operable and monitorable at strategically selected assets.

- **Bilateral contracts** between the DSO and the PED/DER owners are mandatory for the realization of this use case. Such bilateral agreements concern the provision of monitoring and control capabilities from the PED/DER directly to the DSO.
- **Information about grid configuration:** In order for the IPMA to detect an island and to devise a mitigation strategy, the grid configuration, locations and operational status of DERs, PEDs and circuit breakers have to be known by the IPMA.

Use case diagram

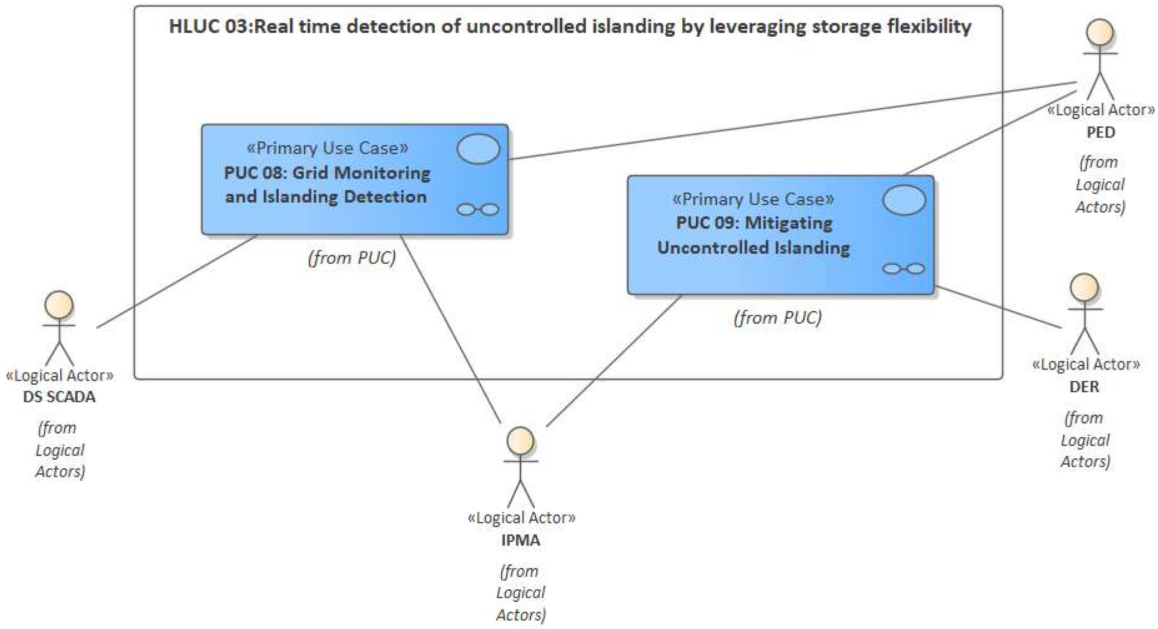

Figure 13: Use case diagram of HLUC 03

3.4.1.4 HLUC 04: Self-healing operation after critical event considering DER & grid flexibility

Scope

The scope of this use case is the mitigation of a faulted grid area. Self-healing is a general concept that denotes the resilience of power systems. It embraces the control and scheduling (near real time) strategies to ensure reliability of power grid and uninterrupted power supply that requires enhanced observability and control capabilities.

Two remedial mechanisms are considered in this use case, the grid reconfiguration by modifying properly the network switchgears and the procurement of DER active energy flexibility offered by Flexibility Service Providers via either bilateral contacts or flexibility markets to avoid network operational issues after reconfiguration.

Objectives

The objective of this use case is to consider the usage of advanced and/or extend existing grid tools for managing the network operation under critical conditions (including extreme weather conditions) aiming to increase the security and resilience of the distribution grid.

Actors

DSO Toolbox – Self Healing Application (SHA), Distribution Management System (DMS), Weather Forecaster (WF), Flexibility Service Consuming Agent (FSCA), Flexibility Service Providing Agent (FSPA), Flexibility Trading Platform (FTP), Flexibility Management System (FMS), Switchgear Dispatch Scheduler (SDS), switchgear, Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Energy Management System (EMS)

Short Narrative

This use case intends to give response for temporary events, including those provoked by extreme weather conditions as strong wind episodes or storms, causing temporary and localized affectation to the grid (outage). Self-healing process after fault occurs in the network entails the identification of the grid boundaries affected by the fault and the extraction of a mitigation plan, in terms of both grid and DER flexibility, to minimize the isolated area and maximize the electrified grid end-users.

Complete Narrative

Self-healing applies when a fault in the grid, i.e. a short circuit due to some external factor (e.g. degradation of cable, accidents, extreme weather episodes, etc.), activates the protection systems (fuses, relays) to isolate the fault by disconnecting the affected line. Also protection elements of DER installed in the same feeder should react and stop injecting to the grid. During the outage, the customers fed by that line are affected by the supply interruption.

The Self-Healing Application (SHA), which is a component of the DSO Toolbox to be developed within the framework of the project, is responsible for the self-healing process.

The first step of the self-healing process is the fault detection, the identification of the affected grid boundaries (i.e. lines, switchgears, sources and prosumers to be considered) and the estimation of the duration of the fault mitigation based on monitoring data provided by the DS-SCADA.

Upon fault detection, the SHA performs a power flow analysis for limiting the islanded network area as close to the fault as possible and maximizing the number of electrified grid end-users. The mitigation plan considers primarily the grid reconfiguration and the DER flexibility procurement as supplementary action if required.

Grid reconfiguration entails the proper scheduling of the switchgear's operational status in order to modify the network power flows such that the number of non-electrified grid end users is the minimum possible. The Switchgear Dispatch Scheduler (SDS) is the responsible application for ordering and assessing the switchgear status modification through the SCADA system (DS- SCADA) and at the time established in the schedule.

In case that grid reconfiguration provokes additional network operational issues, i.e. network congestion or voltage excursions, the flexibility offered by the dispatchable DER units is exploited. Reconfiguration will be applied after the agreement with the Flexibility Service Provider for the provision of flexibility. The flexibility needs in terms of active power and spatial details are extracted by the analysis performed by the SHA and are communicated to the Flexibility Service Providers either directly (bilateral contracts) or via a local flexibility market operated by an independent Market Operator. The Flexibility Service Consuming Agent of the DSO (FSCA) is responsible for realizing such interactions.

The flexibility needs of the DSO are matched with the flexibility bids offered by the Flexibility Service Providers via an auctioning mechanism (Flexibility Trading Platform - FTP). The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO, including also the spatial-temporal requirements, are considered.

The extraction and trading of the flexibility capacities from DER/PEDs are managed by the local Energy Management System (EMS) and the local Flexibility Service Providing Agent (FSPA). The extracted DER flexibilities are managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS).

Preconditions and Assumptions

- **Bilateral contracts** are adequately defined so as to contain all the details (i.e. flexibility capacity, spatial indication of DERs relevant to electricity grid, etc.) for activating the flexibility in every situation requested by the DSO.
- **Spatial component of flexibility:** The flexibility offered by DER assets and the one requested by DSOs should be correlated with their location in the distribution grid since congestion issues have local and not systemic characteristics.
- **Predefined boundaries of the network fault:** the process for identifying the grid boundaries of the fault (i.e. lines, transformers, switches, etc.) and the fault duration ill not be delivered within the framework of this project. Thus, the fault boundaries should be defined a-priori.

Use case diagram

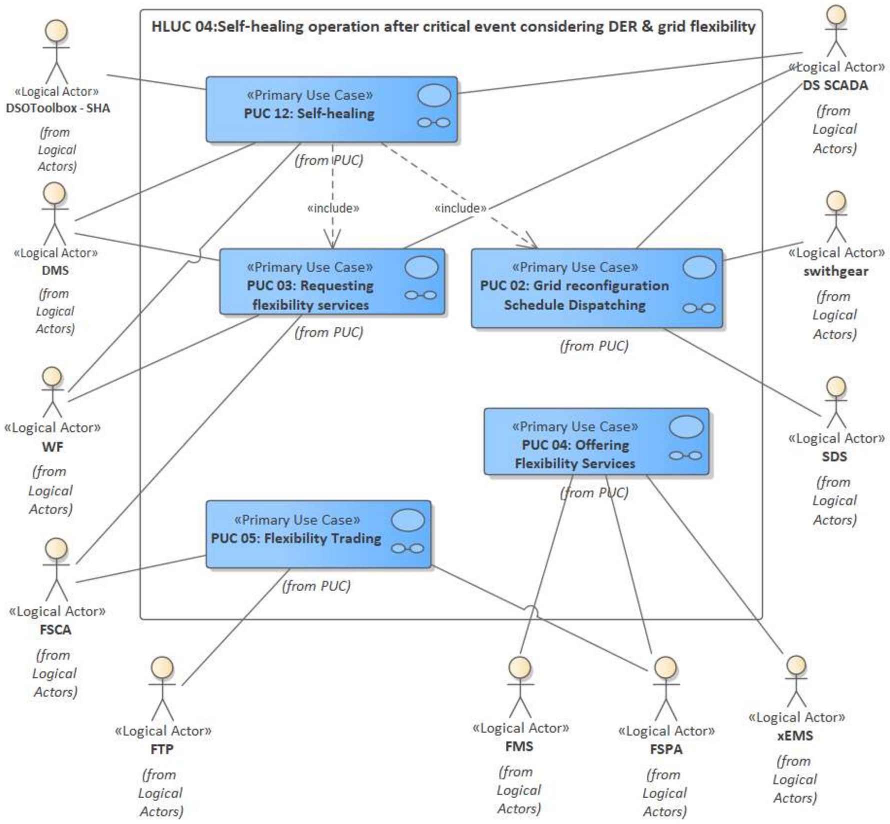

Figure 14: Use case diagram of HLUC 04

3.4.1.5 HLUC 05: Flexibility exploitation for islanded microgrid operation

Scope

This use case aims to leverage flexibilities within an islanded microgrid in order to secure supplies and the economic operation until the reconnection with the upper grid.

Objectives

The objective of this use case is to ensure the power security of an islanded microgrid and increase the reliability of the distribution network.

Actors

DSO Toolbox, Distribution Management System (DMS), Weather Forecaster (WF), Microgrid FMS (MgFMS), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), DSO Toolbox

Short Narrative

Microgrid can operate either in interconnected or in islanded mode. DSO can benefit from microgrid islanding operation, as critical loads within the islanded area will remain connected, aiming to the maximum possible power supply reliability. In islanding operation, the Microgrid Operator (MgO) can leverage the flexibility capabilities within microgrid context to ensure security of supply within microgrid and ensure the reliability of the distribution grid. The storage converters support the islanding operation by providing voltage and frequency references as well as serve the critical loads by offering flexibility when possible. The Microgrid Flexibility Management System (MgFMS) schedules the available DER flexibility so as to keep the energy cost as low as possible.

Complete Narrative

Uncontrolled islanding of a microgrid can impose a number of human safety and equipment damaging risks among others. In addition to the typical Loss-Of-Mains (LOM) risks, DSO will have to face penalties due to the compromised performance against its targets for the number of customers interrupted (CI) and the number of customer minutes lost (CML). Therefore, in order to mitigate such a phenomenon, DSO can leverage the flexibility services via a bilateral agreement with the Microgrid Operator (MgO). The latter extracts flexibility from prosumers, via also bilateral contracts, in order to manage a number of converter-based assets. By this way, the DSO will be able to ensure power supply continuity of critical loads (and thus avoid associated penalties) as well as retain the voltage and frequency of the islanded microgrid within the limits dictated by Grid Code.

The islanded operation of the microgrid is initiated upon the disconnection of the microgrid from the electricity grid at the Point of Common Coupling (PCC). This islanded detection can be identified by the McO based on real measurements acquired from the PCC or by the DSO via the DS-SCADA, DMS and DSO Toolbox applications. In the latter case, an islanding notification should be forwarded to the MgO.

When islanding operation initiates, the MgO leverages local flexibility to serve the most critical loads. Initially, the Microgrid Flexibility Management System (MgFMS) collects actual and forecasting generation and consumption data in order to schedule the required flexibility measures required for the islanding operation. The first priority is to maintain voltage and frequency within acceptable limits and then apply the appropriate management in order to ensure the connection stability of the critical loads.

Preconditions and Assumptions

- **Uncontrolled islanding has been detected and the microgrid transferred to the islanded operation:** The mechanisms for detecting the uncontrolled islanding are not within the scope of this use case. It is considered that the microgrid is already disconnected from the distribution grid. The FEVER solution for detecting islanding conditions is described in HLUC 03: "*Leveraging the flexibility of the storage assets for real time detection of uncontrolled islanding*". An external triggering event will be considered to initiate the use case.
- **The priority order of the microgrid loads is predefined:** Under islanded conditions, the MgO exploits the production units and storages within the context of microgrid to serve local energy needs. In case that local production can partially serve the consumption, the loads will be electrified in priority order ensuring that the most critical loads are primarily served.

Use case diagram

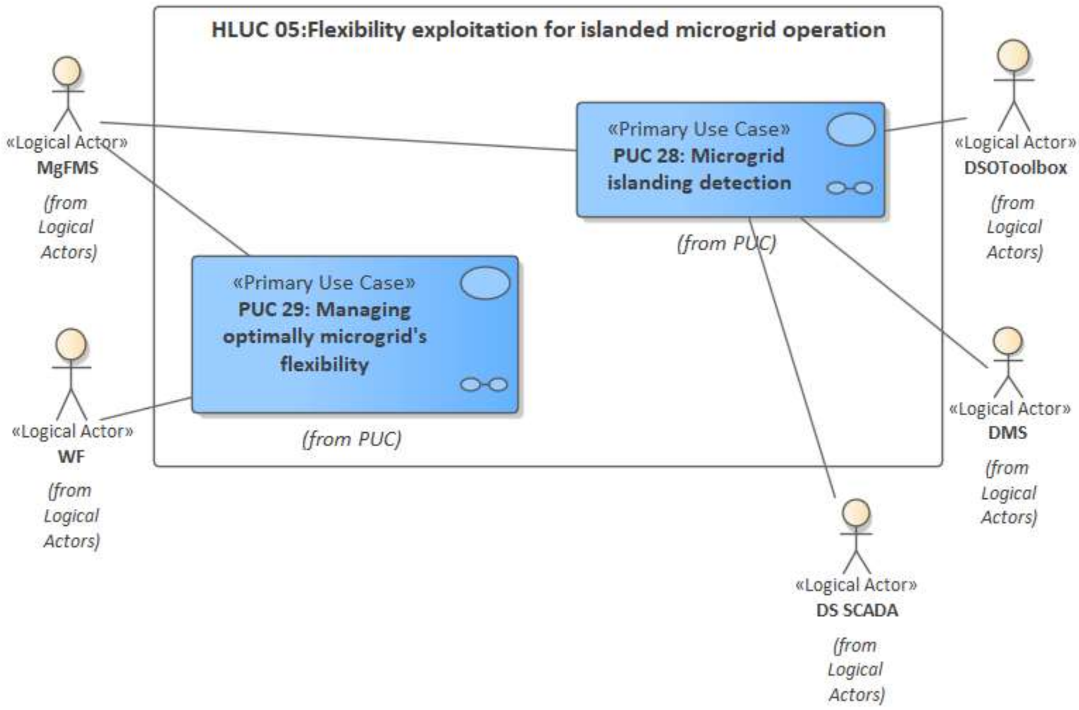

Figure 15: Use case diagram of HLUC 05

3.4.1.6 HLUC 06: Leveraging DER flexibility towards enhancing network operational efficiency

Scope

The scope of this use case is the exploitation of the flexibility offered by distributed energy resources towards increasing network operational efficiency under high RES share conditions. The network efficiency will be assessed in terms of network technical losses reduction.

The procurement of DER flexibility offered by Flexibility Service Providers will be realized via either bilateral contacts or flexibility markets.

Objectives

The objective of this use case is the exploitation of flexibility from distributed resources for minimizing the network technical losses and increasing network operational efficiency. DSOs will gain financial benefits by avoiding regulated penalties for increased network losses.

Actors

DSO Toolbox – Loss Reduction Application (LRA), Weather Forecaster (WF), Distribution Management System (DMS), Flexibility Service Consuming Agent (FSCA), Flexibility Service Providing Agent (FSPA), Flexibility Trading Platform (FTP), Flexibility Management System (FMS), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Energy Management System (EMS)

Short Narrative

Under a high RES penetration scenario in distribution network, there is a need for increasing the local consumption of RES production at primary or secondary substation level. The exploitation of dispatchable distributed production/consumption/storage assets for better matching the consumption and generation profiles locally as well as for shedding network peak demands will enable better exploitation of the existing grid capacity.

Complete Narrative

The Loss Reduction Application (LRA), which is a component of the DSO Toolbox to be developed within the framework of the project, is responsible for extracting the flexibility needs which will enable the flattening of the network demand curve measured at substation level and will result in the minimization of the network technical losses.

Depending on the pre-defined time horizon, an energy forecast of the production and consumption profiles in the grid area under study is required in order to identify the unbalances between generation and demand. These forecasted profiles are provided by the Energy Forecaster (EF) using forecasted weather data form an external weather agency as well as historical monitoring data provided by the AMI and the DS-SCADA.

The forecasted generation and consumption profiles are communicated to the Grid Operation Planner (GOP) which identifies the generation-consumption unbalances in terms of time, amount of energy and related grid area. Afterwards, the GOP extracts the flexibility needs (energy production and consumption) for specific time instances and for specific grid areas.

The flexibility needs generated by the GOP are communicated to the Flexibility Service Providers either directly (bilateral contracts) or via a local flexibility market operated by an independent Market Operator. The Flexibility Service Consuming Agent of the DSO (FSCA) is responsible for realizing such interactions adhering to the communication principles and specifications imposed by the flexibility markets or bilateral agreements.

The flexibility needs of the DSO are matched with the flexibility bids offered by the Flexibility Service Providers via an auctioning mechanism (Flexibility Trading Platform - FTP). The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO, including also the spatial-temporal requirements, are considered.

The extraction and trading of the flexibility capacities from distributed, dispatchable energy resources are managed by the local Energy Management System (EMS) and the local Flexibility Service Consuming

Agent (FSCA). The extracted DER flexibilities are managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS).

Preconditions and Assumptions

- **Bilateral contracts** are adequately defined so as to contain all the details (i.e. flexibility capacity, spatial indication of DERs relevant to electricity grid, etc.) for activating the flexibility in every situation requested by the DSO.
- **Spatial component of flexibility:** The flexibility offered by DER assets and the one requested by DSOs should be correlated with their location in the distribution grid since congestion issues have local and not systemic characteristics.

Use case diagram

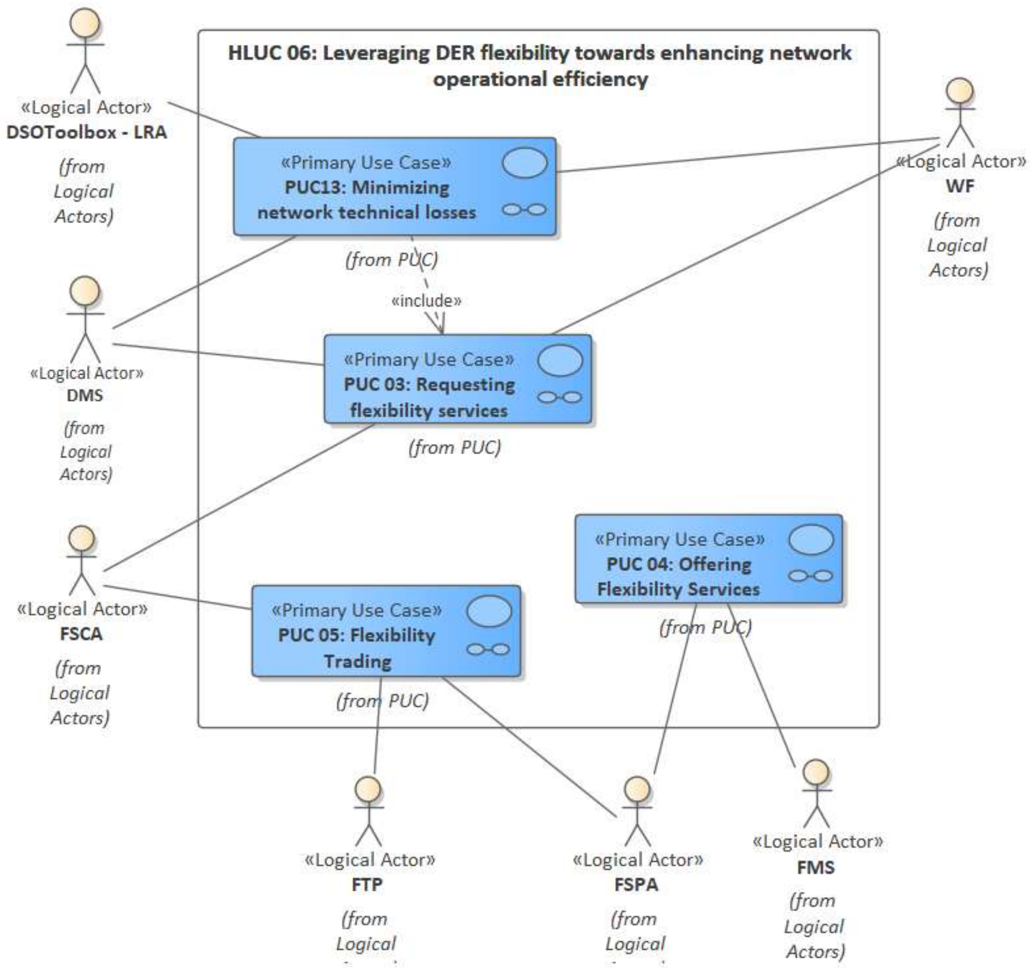

Figure 16: Use case diagram of HLUC 06

3.4.1.7 HLUC 07: Improving power quality and reducing losses through power electronics

Scope

The scope of this use case is to improve the power quality and, consequently, to reduce the technical losses of the distribution network in respect to the network quality standards dictated by the Network Codes. This will be achieved by exploiting distributed PED/DER assets for monitoring and compensating harmonics and phase asymmetries.

Objectives

The objective of this use case is to enhance network operational efficiency, in terms of technical network power losses, and to ensure power quality of supply.

Actors

DSO Toolbox – Power Quality Service (PQS), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA), Power Electronic Devices (PED), Distributed Energy Resource (DER)

Short Narrative

This UC provides a high-level description of the process for improving power quality (in terms of waveform quality) by making use of the PEDs which provide the requested monitoring and control capabilities. The Power Quality Service (PQS) according to the grid monitoring and observability proposes an optimal scheduling for power quality operation of the PEDs. The schedule is executed by PEDs. The remuneration of power services offered by PED owners is realized through bilateral agreements with the DSOs, after strategic allocation analysis, facilitating remote monitoring and control access of PEDs.

Complete Narrative

The PEDs measure locally the electrical parameters of the grid, i.e. voltage, currents, active/reactive power, harmonics, etc., in a continuous way. These field measurements are forwarded to the PQS.

The electrical data from the PEDs is analyzed by the PQS in order to detect power quality issues.

In case of power quality issues in respect to the network quality standards dictated by the Network Codes, the PQS will be triggered. The PQS defines a mitigation plan for the PEDs by performing a phase power flow and harmonic analysis of the grid along with a deterministic optimization of the PEDs operation considering their technical specifications.

The mitigation plan defined by the PQS is communicated via the DS-SCADA to the PEDs which are responsible for executing the ordered operational set-points.

Preconditions and Assumptions

- **Availability of real time data at PED/DER level**: Close to real time measurements are required for the analysis of the network operation. In light of this, PEDs must have been installed and be operable at strategically selected assets.
- **Bilateral contracts** between the DSO and the PED owners are mandatory for the realization of this use case. Such bilateral agreements concern the provision of monitoring and control capabilities from the PEDs/DERs directly to the DSO.
- **Information about grid configuration:** In order for the PQS to devise a mitigation strategy for the improvement of power quality, the grid configuration, locations and operational status of DERs, PEDs and circuit breakers have to be known by the PQS.

Use case diagram

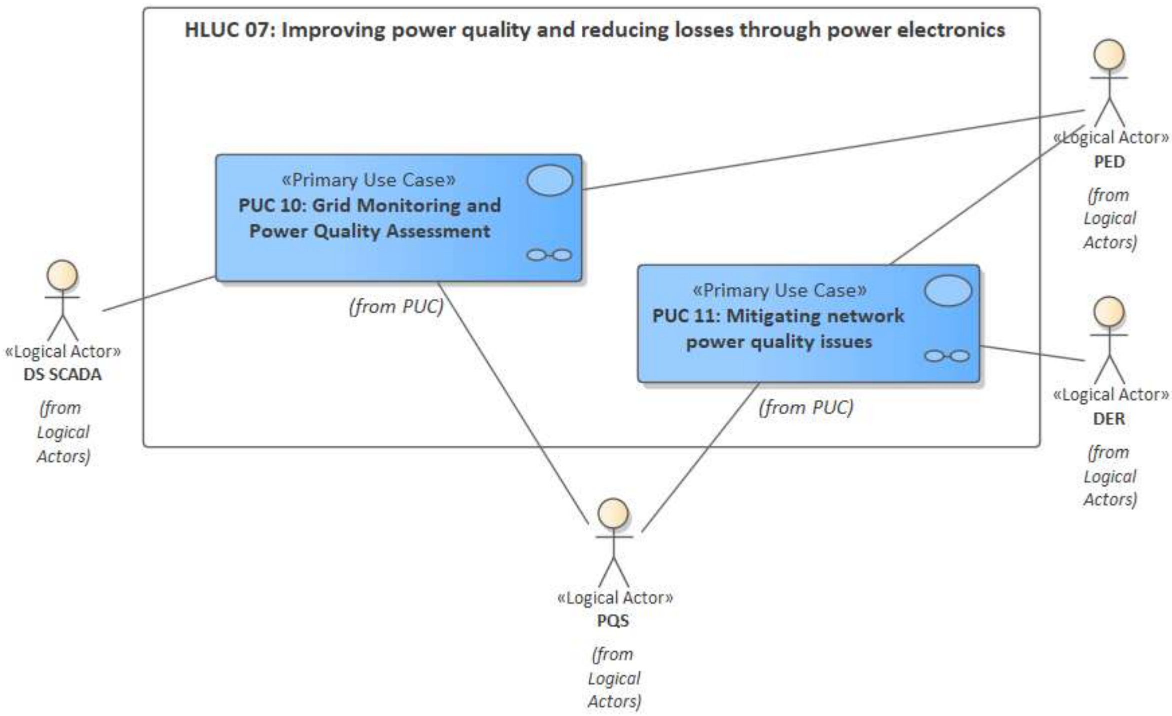

Figure 17: Use case diagram of HLUC 07

3.4.1.8 HLUC 08: Economically optimized flexibility leveraging for a grid-connected microgrid

Scope

Main scope of this use case is to manage/schedule dispatchable DER assets (consumption/production/storage) at microgrid level to achieve economically sustainable and system-wide flexibility solutions to support the utility grid e.g. in addressing net load ramping.

Objectives

The objective of this use case is to optimize the microgrid operation for providing flexibility services to the DSOs via flexibility market.

Actors

DSO Toolbox, Distribution Management System (DMS), Flexibility Service Consuming Agent (FSCA), Flexibility Trading Platform (FTP), Weather Forecaster (WF), Microgrid FMS (MFMS), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA)

Short Narrative

This use case aims to highlight the role of a microgrid as a Flexibility Service Provider offering flexibility services to support network operation. The primary consideration of the Microgrid Operator (McO) when scheduling microgrid's flexibility capacities is to minimize expenditure and maximize flexibility trading associated revenue, while ensuring that all systems are functional and there are no noticeable inconveniences. At the same time, prosumers within the microgrid context trade their flexibility having in mind to minimize their energy bills and/or maximize their profits from trading. This use case focuses on the McO's objective to achieve the most economically effective flexibility solution serving DSOs flexibility request, aiming to maximize the trading profits and at the same time maintain the operation costs in the lowest possible levels.

Complete Narrative

The DSO monitors and plans the grid operational status based on real monitoring data from the DS-SCADA and forecasted consumption/production profiles. In case that abnormal operational conditions are identified, the DSO extracts the required mitigation plan considering grid conventional management solutions (ex. grid reconfiguration, load tap changers, etc.) as well as the procurement of flexibility offered by DERs connected to the distribution grid. The flexibility needs in terms of active/reactive power extracted by the grid analysis performed by the DSO Toolbox and DMS are communicated by the Flexibility Service Consuming Agent (FSCA) to the Flexibility Service Providers via a local flexibility market operated by an independent Market Operator.

The role of the Flexibility Service Provider is undertaken by the Microgrid Operator (MgO). The MgO via the Microgrid Flexibility Management System (MgFMS) synthesizes a flexibility schedule. Based on the spatial short-term load and generation forecasting profile in respect to the weather forecast data provided by the Weather Forecaster (WF), the MgFMS develops a local optimization strategy and informs the prosumers within the microgrid context concerning the operational status modification of the DERs in order to serve the grid flexibility needs.

The flexibility needs of the DSO are matched with the flexibility bids offered by the MgO via a trading mechanism (Flexibility Trading Platform - FTP). The bid(s) of the MgO matching partially or completely the energy flexibility needs of the DSO are concluded.

Preconditions and Assumptions

- **The grid flexibility needs are predefined:** This use case focuses on the microgrid processes and tools required for scheduling flexibility and supporting network operation. In light of this, **i**t is assumed that DSO has already defined its flexibility needs exploiting its legacy systems (DS-SCADA, DMS, etc.) as well as the advanced monitoring and management applications of the DSO Toolbox developed within this project. The DSO's aspects are considered in HLUCs 01 and 02.

Use case diagram

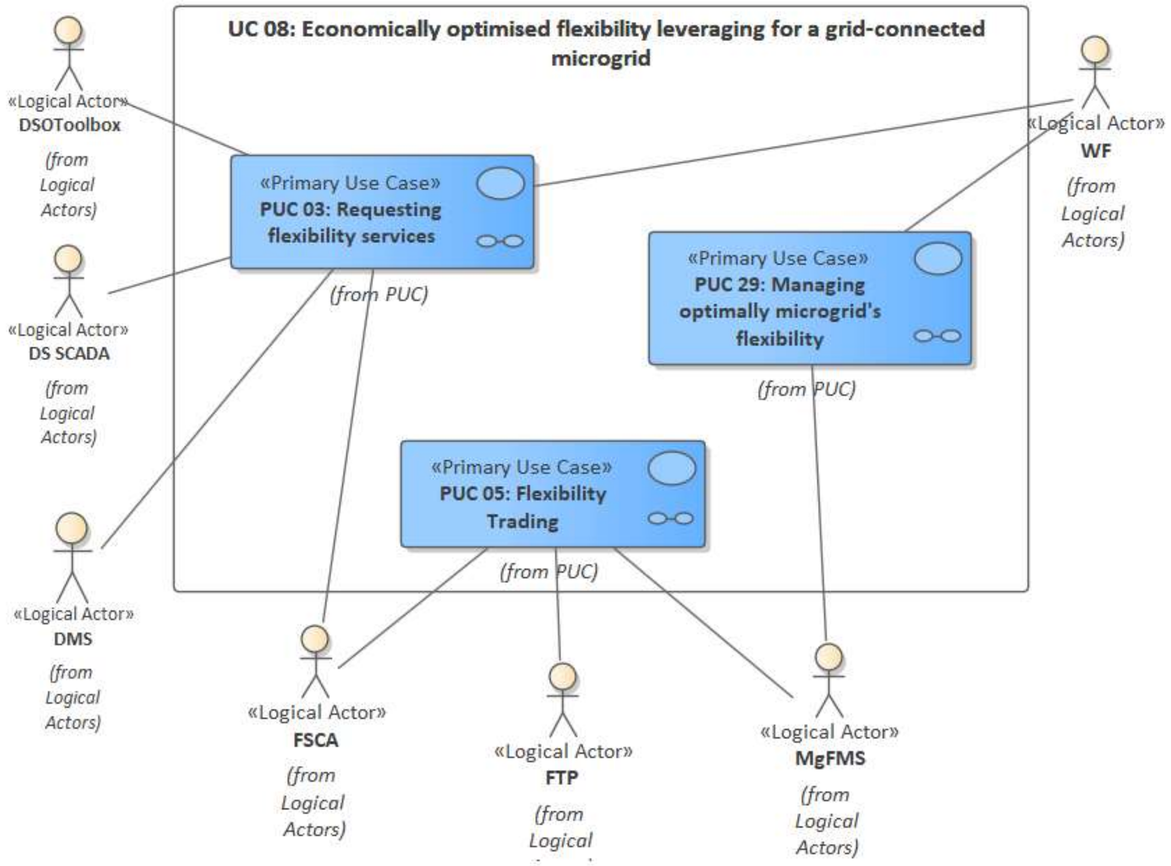

Figure 18: Use case diagram of HLUC 08

3.4.1.9 HLUC 09: Day-ahead market mechanisms incentivizing energy flexibility

trading for mitigating problems of the transmission system & distribution network, integrating wholesale and retail markets

Scope

The scope of this use case is to incentivize the trading of energy flexibility located on both the transmission & distribution grid on a day-ahead level. In order to enhance the robustness and functionality of the market, the transmission & distribution constraints are integrated in the market modelling. This way the derived market schedules are feasible and will incur lower real-time imbalances. The market mechanism will produce Locational Marginal Prices at T/D nodes/areas as a means to foster flexible retail pricing schemes.

Objectives

The objective of this use case is to provide a day-ahead centralized wholesale market mechanism to exploit the flexibility sitting in both the transmission system & distribution grid. The day-ahead market offers innovative energy products which can foster the participation of flexible resources in the day-ahead market (e.g. storage demand response, etc.). The day-ahead market is operated by the Market Operator (MO).

Actors

Day-Ahead Market Scheduler (DAMSc), Bidding Application, Power Flow Simulator (PFS), Day-Ahead Market Schedule Disaggregation Application (DAMSDA), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA and Transmission System (TS-SCADA), Network Data Processing Application (NDPA)

Short Narrative

The use case implements centralized day-ahead wholesale market mechanisms operated by the Independent Market Operator (IMO), for exploiting flexibility located both at the transmission & distribution network. An iterative market clearing solution facilitates the trading of energy, in order to match supply with demand at day-ahead level, and incorporates grid constraints provided by the TSO & DSO to ensure market schedule feasibility and to improve congestion management. Locational Marginal Prices at T&D nodes/areas can be used to provide flexible pricing schemes, providing a link to the retail market.

Complete Narrative

The Day-Ahead Market Schedule (DAMSc) implements a day-ahead market which is a mandatory pool or power exchange where the market model clears buy and sell orders using marginal pricing. The DAMSc receives the bids of the market participants and solves the day-ahead market which outputs the market schedules of BSPs and BRPs considering constraints of the transmission system.

The participation in the day-ahead market follows specific market rules and restrictions. The Bidding Application (BA) is responsible for defining the bidding strategies of BRPs and BSPs, i.e. it constructs the appropriate order type (e.g. Reversible Block Order) which is submitted to the Day-ahead Market Scheduler.

The prequalification of the market schedule at distribution level in order to ensure that network operational constraints are not violated requires the disaggregation of this schedule at nodal/area level of the distribution system by the Day-ahead Market Schedule Disaggregation Application (DAMSDA). The disaggregated profiles are introduced to the Power Flow Simulator (PFS) which performs an optimal power flow at the distribution system to identify potential network operational issues. Possible requested modification of the market schedule ensuring the secure and reliable operation of the distribution grid are forwarded to the DAMSc in order to re-solve the day-ahead market and output the final day-ahead market schedules.

The network technical specifications (i.e. topologies, thermal limits, voltage boundaries, etc.) are provided by the TS-SCADA and DS-SCADA systems of TSO and DSO. This data can be provided in a standardized way (Common Information Model – CIM) or other data format. The integration of such data in a unified way to the DAMSc might require the pre-processing of the source data by the Network Data Processing Application (NDPA).

Preconditions and Assumptions

- **Pre-defined Bidding Strategies:** the optimal bidding strategy of the market participants, i.e. BRPs and BSPs, is out of the project's focus. The day-ahead market bids will be a-priory defined based on offline market data.

Use case diagram

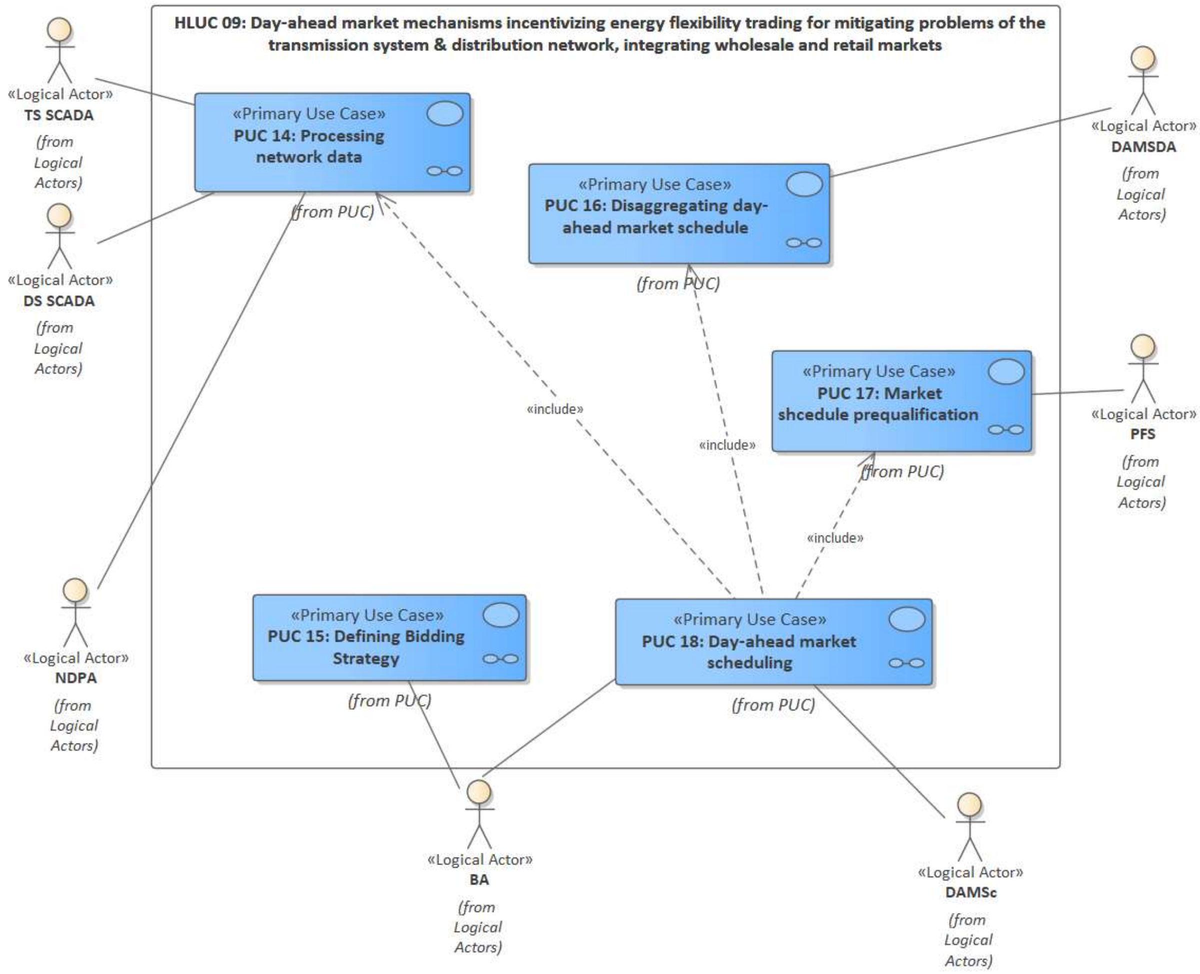

Figure 19: Use case diagram of HLUC 09

3.4.1.10 HLUC 10: Intra-day market mechanisms incentivizing active & reactive energy flexibility trading for mitigating problems of the distribution network

Scope

The scope of this UC is to incentivize the trading of active and reactive energy flexibility located at the distribution grid at an intra-day level in order to address issues of the distribution grid. On a continuous level the DSO identifies anticipated network issues and requests the flexibility from the market at the needed location and time. The Flexibility Service Providers aims to provide the needed flexibility from its available resources at the specific location.

Objectives

The objective of this use case is to provide an intra-day flexibility market mechanism to exploit the flexibility sitting in distribution grid for grid operation support.

Actors

Intra-day Flexibility Trading Mechanism (IDFTM), Flexibility Service Consumer Agent (FSCA), Flexibility Service Provider Agent (FSPA)

Short Narrative

This use case implements intra-day market mechanisms operated by the IMO, for exploiting flexibility from the distribution network, in order to address network issues on a continuous level. The DSO identifies anticipated network issues and requests flexibility for active & reactive energy at specific time & grid location. The Flexibility Service Providers offer flexibility to match the DSO needs.

Complete Narrative

The target of this use case is the development and testing of a new intra-day market mechanism being implemented after the solution of the Day-Ahead Market and before the real-time market mechanisms. The market products will be the active and reactive energy at specific location and time. The full set of product requirements will be specified along the development of the relevant market tool.

The DSO identifies potential grid issues and requests the necessary flexibility from Flexibility Service Providers via the IDFTM. The flexibility needs and the flexibility offers are constructed and communicated to the Market Operator by the FSCA and the FSPA, respectively, adhering to the principles and restrictions imposed by the intra-day market. The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO, including also the spatial-temporal requirements, are considered.

This use case is focusing on the development of the intra-day mechanism. Thus, the processes of extracting flexibility from DERs as well as the ones for defining the flexibility needs of DSO’s to support network operation are out of the scope of this use case. However, these processes are defined within the context of other use cases of this document.

Preconditions and Assumptions

- **Spatial component of flexibility:** The flexibility offered by DER assets and the one requested by DSOs should be correlated with their location in the distribution grid since distribution system issues have local and not systemic characteristics.
- **Flexibility needs are predefined by the DSO:** it is assumed that DSO has defined its flexibility needs based on its legacy systems as well as the advanced monitoring and management applications of the DSO Toolbox developed within this project. More details can be found in HLUCs 01-07
- **Flexibility offers are predefined:** it is assumed that the flexibility bids extracted from the prosumers are already defined based on either simulated or offline market data. More details on the DER flexibility extraction can be found in HLUC 08 and HLUCs 12-15.

Use case diagram

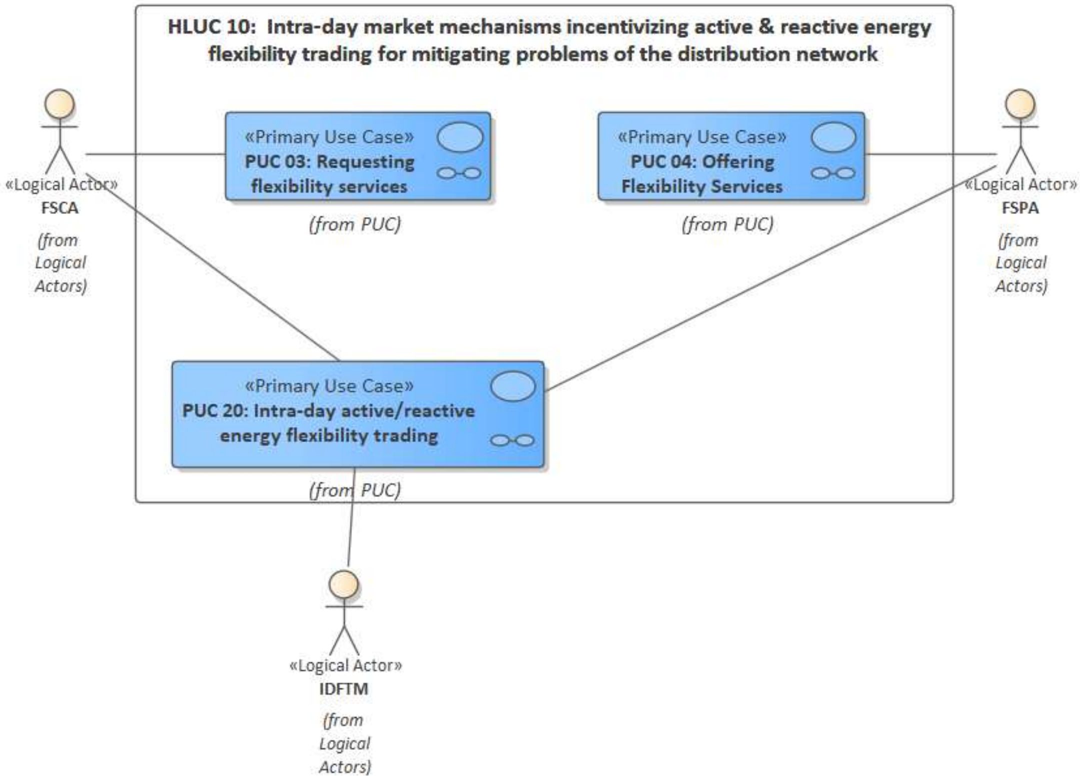

Figure 20: Use case diagram of HLUC 10

3.4.1.11 HLUC 11: Real-time market mechanism incentivizing energy & capacity flexibility trading from BSPs, to address balancing and T&D congestion management, integrating wholesale and retail markets

Scope

The scope of this UC is to incentivize the real-time trading of balancing energy & reserve capacity flexibility located on both the transmission & distribution grid. The prosumer is the main Balance Service Provider actor who sells reserve capacity that the TSO/DSO need to buy, and trades balancing energy to cover the imbalances of non-dispatchable resources. In order to enhance coordination, the transmission & distribution constraints are integrated in the market modelling. This way the dispatch instructions are feasible and instructed deviations can be reduced. The market model yields Locational Marginal Prices at T/D nodes/areas as a means to foster flexible retail pricing schemes.

Objectives

The objective of this use case is to provide a common TSO/DSO market where a clearing platform will foster the integration of energy flexibilities located on both transmission and distribution grids into balancing electricity market considering transmission and distribution network constraints, simultaneously.

Actors

Real-Time Balancing Market Mechanism (RTBMM), Bidding Application (BA), Supervisory Control and Data Acquisition system for Distribution System (DS-SCADA and Transmission System (TS-SCADA), Network Data Processing Application (NDPA).

Short Narrative

This use case implements centralized real-time market mechanisms operated by an Independent Market Operator for exploiting flexibility from the transmission system and distribution network in order to balance demand with supply and manage congestion. The flexibility is bought by the System Operators (TSO/DSO) in the form of balancing energy and reserve capacity on a real-time basis. The flexibility is provided by the Balance Service Providers (BSPs) who offer flexibility located at both the transmission and distribution level.

Locational Marginal Prices at T&D nodes/areas can be used to provide flexible pricing schemes providing a link to the retail market.

Complete Narrative

The real-time balancing market implemented in this use case belongs to the common TSO/DSO flexibility market mechanisms presented in section 2.3 “Models enabling DSOs to access flexibility” and it is a balancing and congestion management platform for computing real-time balancing actions and Distributed Locational Marginal Prices (DLMP) for retail markets.

The goal of the real-time market platform is to integrate congestion management and balancing throughout the transmission and distribution system. The resulting price signals provide locational investment signals that attract investment in needed technologies, as well as signals for reinforcing the network wherever this is required. The platform promotes economic efficiency by matching orders that benefit from trade, and by coordinating the operations of balancing and congestion management. The produced DLMPs prevent market manipulation through increase-decrease (INC-DEC) gaming by exposing agents to a locally uniform price signal and overcoming the well-known manipulation opportunities that result from zonal pricing.

The participation in the real time balancing adheres to specific market rules and restrictions. The Bidding Application (BA) is responsible for defining the bidding strategies of BRPs and BSPs, i.e. it constructs the appropriate order, comprising at least a real power quantity and a price, which is submitted to the real-time balancing market.

In order to ensure the exploitation of available flexibility capacity/energy, irrespectively of the grid level it is located, without provoking any network operational issue, the technical specifications and operational limitations for both transmission and distribution grids should be integrated in the balancing market mechanism. The network technical specifications (i.e. topologies, thermal limits, voltage boundaries, etc.) are provided by the TS-SCADA and DS-SCADA systems of TSO and DSO. This data can be provided in a standardized way (Common Information Model – CIM) or other data format. The integration of such data in a unified way to the real-time balancing market might require the pre-processing of the source data by the Network Data Processing Application (NDPA).

This use case is focusing on the development of the balancing/congestion market mechanism. Thus, the processes of extracting flexibility from DERs are out of the scope of this use case. However, these processes are defined within the context of other use cases of this document.

Preconditions and Assumptions

- **Spatial component of flexibility:** The flexibility offered by DER assets should be correlated with their location in the distribution grid since this is necessary for the evaluation of the network operational status upon flexibility activation
- **Flexibility needs and offers are predefined:** it is assumed that that balancing needs as well as flexibility bids are pre-defined based on either simulated or offline market data.

Use case diagram

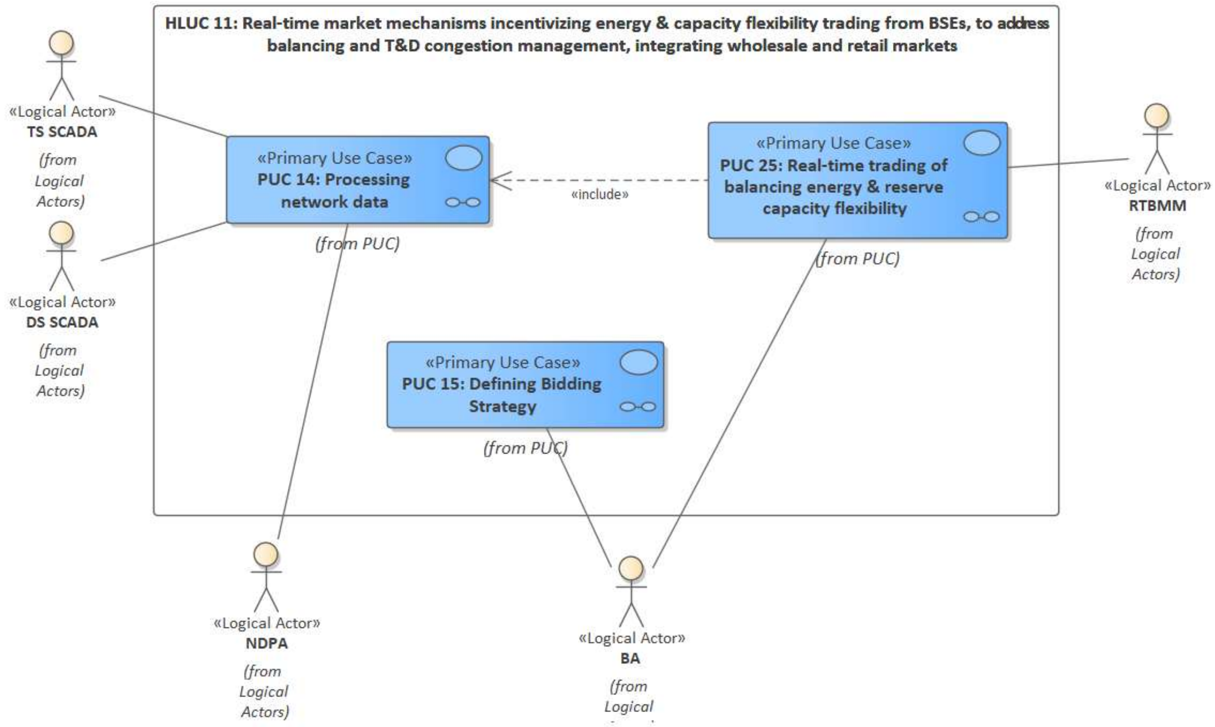

Figure 21: Use case diagram of HLUC 11

3.4.1.12 HLUC 12: Creating dynamic tariffs based on flexibility use in the actual regulatory framework

Scope

The increasing penetration of renewable DERs can be beneficial in relation to the objectives of participating prosumers and consumers on fair shares. One possible tool for a fair participation could be a dynamic tariff-approach, taking into consideration the inputs of all the local players according to the specific and individual technology and readiness levels in combination with the type and size of their respective participation and allowance. This use case is based on the modification of the DSOs existing tariff/pricing systems. The generators of local flexibility on all levels shall be rewarded for their involvement. The DSOs have to create innovative tools for rewarding based on measurements and reference data. The new pricing models have to comply with the existing regulatory framework.

Second task for dynamic tariffing needs to be the remuneration of close down of operational action for DER operators by the DSO in case congestion and predicted grid overload or grid disbalance (i.e. unbalance between energy in-flows and out-flows on the grid) leading to instabilities and finally blackout.

Objectives

The objective of this use case is to provide the mechanism for creating dynamic tariffs based on flexibility use in the actual regulatory framework and remuneration for costs for extraction of flexibilities in the scope of equivalent or actual operative close down in the actual regulatory framework.

Actors

Dynamic Price Definition Mechanism (DPDM), Remuneration Mechanism (RM), Flexibility Service Consuming Agent (FSCA), Flexibility Trading Platform (FTP), Energy Management System (EMS), Flexibility Service Providing Agent (FSPA), Flexibility Management System (FMS)

Short Narrative

This use case implements an advanced dynamic pricing mechanism for the procurement of flexibility in the congestion and overload states of the grid and remuneration for costs of extraction of flexibilities in the scope of equivalent or actual sequential operational close down of DER at distribution level. Capacity-driven network tariffs and time-of-use consumer tariffs which internalize these network tariffs are not tailored for this task, neither in the spatial nor in the temporal dimension. What is sought after is a means of pricing at the distribution level which can potently generate prices with high spatial and temporal resolution. Two governing principles will be employed: i) the pricing has to be dependent on and balanced with the income of the DSO based on avoided cost by TSO to remedy these situations., ii) remuneration to the prosumer has to cover the costs of extraction of flexibilities in the scope of equivalent or actual sequential operational close down of operation of process.

Complete Narrative

The Dynamic Price Definition Mechanism (DPDM) is responsible for defining the dynamic pricing scheme to be implemented for the procurement of the flexibility at distribution level. Dynamic pricing as a matter of settling and billing are not unit processes but are each a group of processes carried out in different roles.

Settling process is included in the combination of FMS and FTP to the level of executed energy flexibility in units constituting the complete price equation: power on stand-by, energy flexibility and time interval. The settling process is carried out by the Flexibility Market operator – depending on the use case, this can be BRP or LMO (or MORB) with the participation of supplier of energy flexibilities (Flexibility Management Operator) and purchaser of energy flexibility (BRP or DSO/subDSO).

The billing process realized by the remuneration mechanism (RM) depends on business model of remuneration of energy flexibility and business model of financing the energy flexibility by different purchasers, in particular the new business model of DSO vs TSO.

Flexibility procurement can be realized by different business actors and different timeframes. For example, BRPs may request flexibility services for balancing their market schedule periodically (up to 15minutes interval) while DSOs might need to procure flexibility near real time in order to support network operation. BRPs can procure balancing services from intra-day or continuous-trading markets, however, this use case focuses on the procurement of flexibility from DER units under dynamic pricing schemes.

The energy flexibility needs are identified by the DSOs and BRPs in terms of power, time and location related to grid topology or balancing area. The flexibility needs are communicated by the Flexibility Service Consuming Agent (FSCA) to the Flexibility Service Providers via the FTP.

The flexibility needs are matched with the flexibility bids offered by the Flexibility Service Providers via the Flexibility Trading Platform - FTP. The bid(s) of the Flexibility Service Providers matching partially or completely the energy flexibility needs of the DSO/BRP, including also the spatial-temporal requirements, are considered. Purchase price, supplied by the DSO is based on the urgency of the situation – based on the real situation on the grid, DSO is able to assess the potential incurred costs for close down (curtailment).

The extraction and trading of the flexibility capacities from distributed, dispatchable energy resources are managed by the local Energy Management System (xEMS) and the local Flexibility Offering Agent (DER-FOA). The extracted DER flexibilities can be managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS). The price of the DER flexibilities is predefined for different levels of incurred costs and consequences of the remedial actions. Flexibility service providers include full incurred costs (as if the close down (curtailment) were to happen) when submitting such an offer. This way they are appropriately remunerated when such an offer is activated.

Preconditions and Assumptions

- **BRP's energy schedule is already defined:** the forecasting and planning of the production/consumption of BRPs within the balancing group has been performed and the schedule has been communicated to the day-ahead market
- **Definition of the flexibility needs:** it is assumed that DSOs and BRPs have defined their flexibility needs based on their legacy monitoring and management systems
- **DSO and DER operators** have agreed on remuneration payments in case of operation close down for DER

Use case diagram

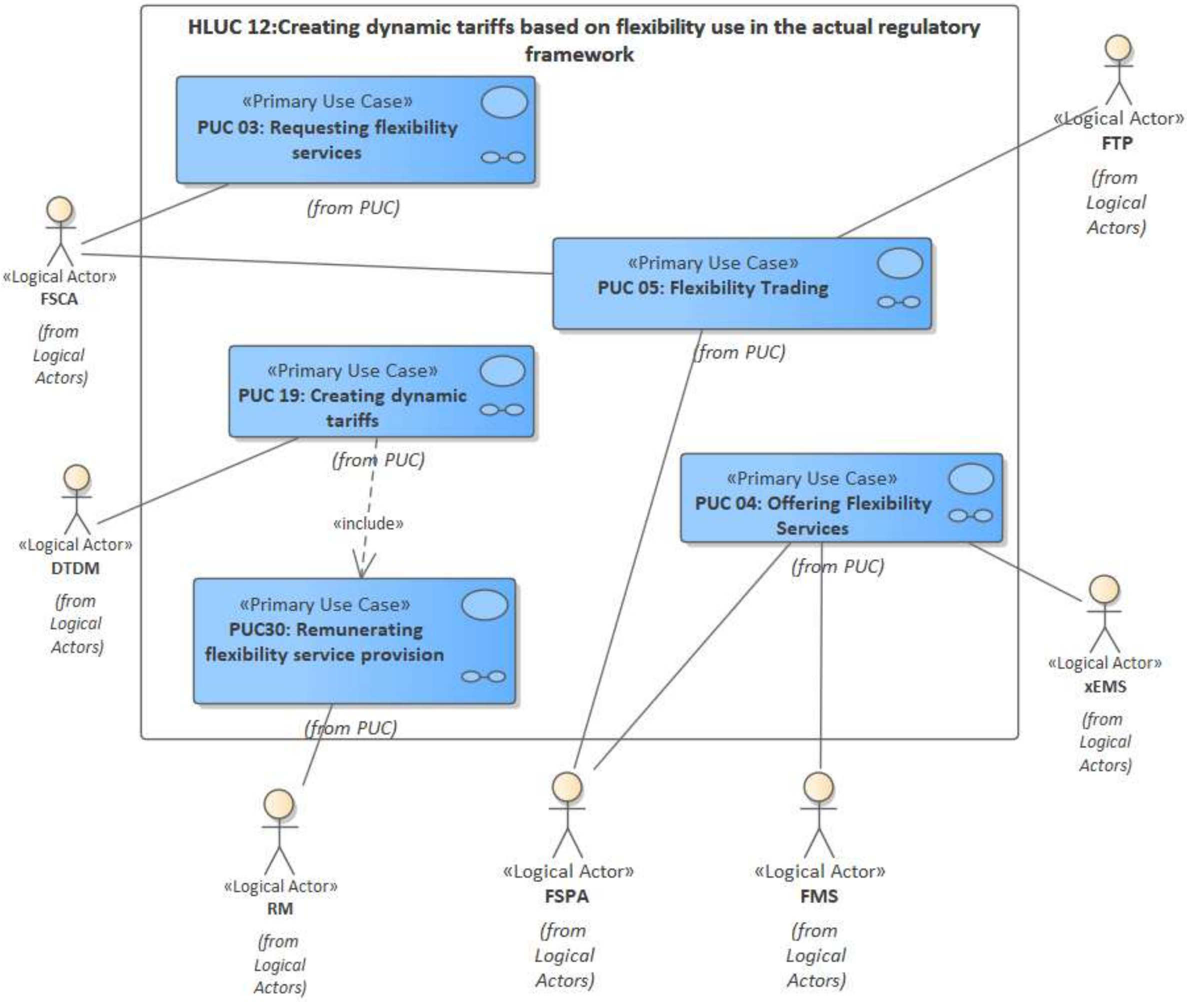

Figure 22: Use case diagram of HLUC 12

3.4.1.13 HLUC 13: Improving the outcome in flexibility by introducing sector coupling

Scope

From a BRP perspective the local balancing regime needs to evolve and maybe even to involve more utilities and decentralized approaches, e. g. natural gas, district heating, CHPs based on DRES at LV-MV levels. This use case aims to facilitate the synergies among the sectors of electricity, heating/cooling and transportation in order to increase the available flexibility capacities within a balancing area and reduce the overall cost of BRP's imbalances.

Objectives

The objective of this use case is to increase the available flexibility capacities within the balancing group achieved by creating synergies among electricity, gas and transportation sectors within a balancing group and consequently to increase BRP's portfolio and can reduce its balancing costs.

Actors

BRP Management System (BRPMS), Flexibility Service Consuming Agent (FSCA), Flexibility Trading Platform (FTP), Energy Management System (EMS), Flexibility Service Providing Agent (FSPA), Flexibility Trading Platform (FTP), Flexibility Management System (FMS), Combined Heat and Power (CHP), Electric Vehicle (EV), Electric Vehicle Supply Equipment (EVSE), Hydrogen Storage System (HSS), Energy Community Flexibility Management System (ECFMS).

Short Narrative

To fully integrate distributed RES into a local LV/MV grid the overall energy production and consumption are to be considered. With the main focus on electricity, the coupling with other sectors of a utility company shall be established for flexibility trading. With the use of CHP systems and other sector coupling technologies (e.g. Power-to-Gas plant) energy/flexibility can be shifted into the sectors gas and heat. The hydrogen converted energy can be converted back into electricity or heat via CHP plants. The overall flexibility extraction process is enhanced with the coupling of the former mentioned sectors aiming to improve the outcomes of the flexibility trading.

Complete Narrative

The extraction of flexibility from dispatchable DERs requires the implementation of advanced management and monitoring processes. The overall flexibility capacity available for trading purposes can be increased when synergies are achieved among different sectors, i.e. electricity, gas, transportation etc.

The extraction of DER flexibilities at prosumer level are extracted by the local Energy Management Systems (EMS) and the Flexibility Service Providing Agent (FSPA) of DERs. The EMS system monitors and manages the energy assets under its responsibility and extracts the potential flexibility that can be offered by the DERs in respect to their operational status and constraints. Different types of energy management systems are considered for the sector coupling, i.e. a Factory Energy Management System (FEMS) controls factories and commercial buildings; a Home Energy Management System (HEMS) controls residential locations; a Charging Energy Management System (CEMS) controls electric vehicle charging stations; a Charging/Discharging Energy Management System (CDEMS) controls an electric vehicle capable of discharging to the grid. The FSPA is responsible for managing the potential flexibilities identified by the EMS and defining the bidding strategy. The bidding strategy comprises the partial selection of potential flexibility to be traded, the temporal and spatial characteristics of the flexibility and the respective activation cost. The extracted DER flexibilities can be managed and traded either individually or in an aggregated way by the Flexibility Management System (FMS).

In case that an energy community is also considered as a member of the balancing group, the available aggregated flexibility of its members, which remains idle after the optimal energy management of the energy community, can be offered to the balancing group it belongs to for balancing purposes. The Energy Community Flexibility Management System (ECFMS) is responsible for externalizing the available flexibility of the energy community.

The bidding profiles of the DER flexibilities are communicated to the Flexibility Trading Platform (FTP) in order to be matched with the BRP's flexibility requests communicated by the Flexibility Service Consumer Agent (FSCA).

Preconditions and Assumptions

- **BRP's energy schedule is already defined:** the forecasting and planning of the production/consumption of BRPs within the balancing group has been performed and the schedule has been communicated to the next level market which is Regional Flexibility Exchange market or MBA-level Intra-day or day-ahead market
- **BRP's unbalances have been identified:** the unbalances between the BRP's day-ahead schedule and the real time energy profile of the balancing group are identified in terms of energy gap and time duration. This process requires the implementation of advanced metering systems.
- **The operation of energy community has been optimized:** a precondition for the integration of an energy community in the BRP's trading process is that energy balance among its members has been achieved in the most optimal way, i.e. cost efficient, greener energy, etc. The energy management of an energy community is realized in a peer-to-peer context within the HLUC 15: *"P2P flexibility trading"*.

Use case diagram

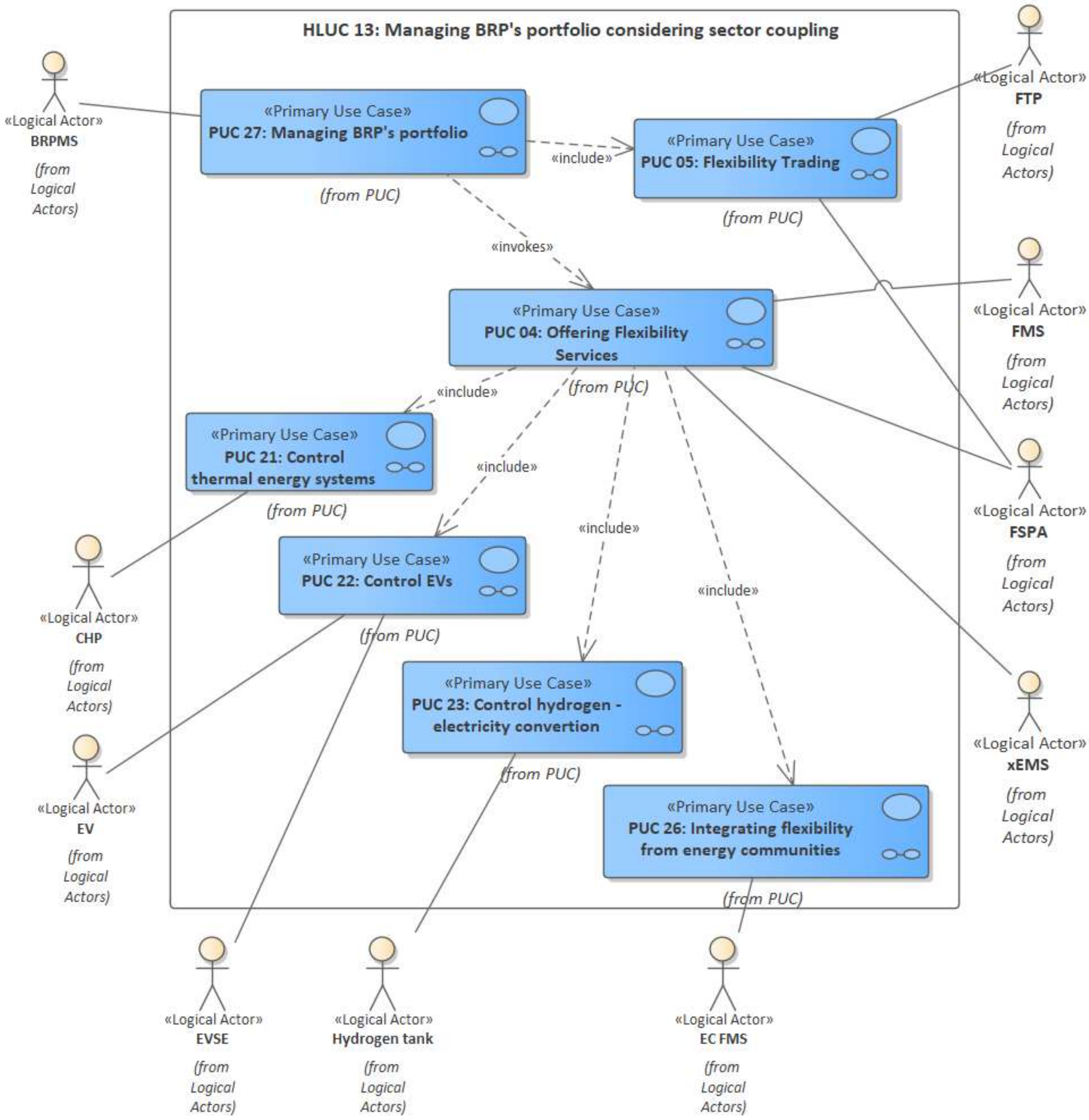

Figure 23: Use case diagram of HLUC 13

3.4.1.14 HLUC 14: Form a first example of a regional flexibility exchange model

Scope

The scope of this use case is the development of a regional flexibility exchange market where available flexibility can be traded among different balancing groups represented by the respective BRPs for balancing purposes. The participation of BRPs in such regional flexibility markets presuppose the internal balancing of the balancing group by the responsible BRP.

Objectives

The objective of this use case is the development of a regional trading mechanisms which will facilitate the trans-regional flexibility trading among BRPs for minimizing their balancing costs.

Actors

Balance Responsible Party Management System (BRPMS), Flexibility Service Consumer Agent (FSCA), Flexibility Service Provider Agent (FSPA), Flexibility Trading Platform (FTP)

Short Narrative

This use case introduces a regional marketplace and marketplace operator for trading energy flexibilities as opposed to trading of energy products. The competitors are BRPs both on supply and demand sides.

This energy flexibility exchange could run in parallel to existing energy exchange and would focus on transients close to real time, reducing the need for tertiary and secondary reserves in the system.

The trading system is operated by an independent Market Operator.

Complete Narrative

The Flexibility Trading Platform (FTP) operated by an independent Market Operator at regional level enables the trading of energy flexibilities among Balancing Groups (BG) coordinated and represented by BRPs.

The initial step for BRP's participation in the regional flexibility market is the internal flexibility management within its balancing group by the BRP Management System (BRP-MS).

In case that the available flexibility pool within the balancing group is not adequate to meet the flexibility needs of the responsible BRP, a second level of flexibility trading among BRPs at regional level is realized. This regional flexibility market facilitates the trading among BRPs with energy flexibility needs which are not fulfilled internally and the BRPs with excess of energy flexibility. The former BRP acts as a flexibility service consumer represented by a Flexibility Service Consuming Agent (FSCA) while the latter acts as Flexibility Service Provider represented by a Flexibility Service Providing Agent (FSPA).

In this use case, an energy community can be considered as Flexibility Service Provider represented by the Energy Community Responsible (ECR). The energy community can offer flexibility services on a regional flexibility market as a member of a BRP's balancing group via the BRP-MS or as a BRP of its own, possibly contracting operative activities to an existing BRP.

Preconditions and Assumptions

- **Flexibility trading within the balancing group is completed:** The participation of the BRPs in the regional flexibility market entails the extraction of their flexibility needs or surplus in respect to the internal management of their balancing group. In this respect, the implementation of the internal BRP's management portfolio realized within the context of HLUC 13: "*Improving the outcome in flexibility by introducing sector coupling*" is a precondition for the implementation of the flexibility trading at regional level.
- **Energy Communities integrated as flexibility service providers within a balancing group:** Since an energy community represents a variety of consumers, prosumers, and producers offering their flexibility and/or dispatchable DERs on the market place, the internal management of an energy community is not within the scope of this use case. This is examined in HLUC 15: "*P2P flexibility trading*" and its successful implementation is a requirement for the integration of energy communities in this use case. Further, the integration of the energy community to the BRP's flexibility trading mechanism should be successfully implemented within the framework of HLUC 13: "*Improving the outcome in flexibility by introducing sector coupling*".
- **BRP's energy schedule is already defined:** the forecasting and planning of the production/consumption of BRPs within the balancing group has been performed and the schedule has been communicated to the day-ahead market
- **BRP's unbalances have been identified:** the unbalances between the BRP's day-ahead schedule and the real time energy profile of the balancing group are identified in terms of energy gap and time duration. This process requires the implementation of advanced metering systems.

Use case diagram

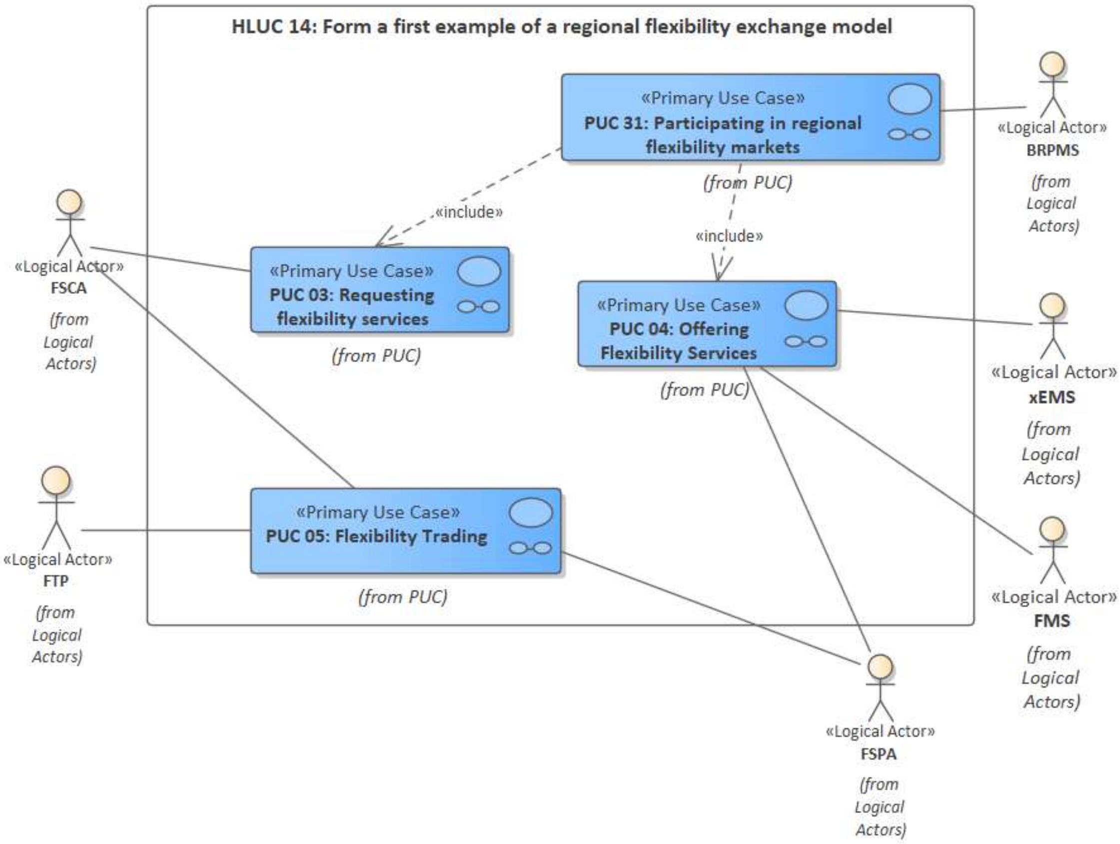

Figure 24: Use case diagram of HLUC 14

3.4.1.15 HLUC 15: P2P flexibility trading

Scope

The use case resides in an eco-system of prosumers, consumers and consumers which form a (local or regional) energy community. While such a community implies a high level of "self-consumption" or "self-supply" inside the community, it strives for an overall system optimum with comprehensive energy supply and consumption orientation, targeting inclusion of all energy vectors.

In contrast to maximizing their profit, the energy communities under consideration in this use case shall provide environmental, economic or social community benefits for their members or the local area. In that respect they are similar to the Citizen Energy Communities or Renewable Energy Communities as described in Art. 16 of the EC Directive on the Internal Market for Electricity Directive on "Citizen Energy Communities" (EMD) or Art. 22 of the EC Directive on the promotion of the use of energy from renewable sources on "Renewable Energy Communities" (RED) respectively.

Objectives

The main objective of the use case is to provide a pilot testing case for two-level trading of energy flexibilities in closed community markets.

Actors

P2P Flexibility Trading Platform (P2P-FTP), Flexibility Trading Platform (FTP), Flexibility Service Providing Agent (FSPA), Flexibility Service Consuming Agent (FSCA)

Short Narrative

This use case will demonstrate automated trading of flexible energies (electricity, heat) in the context of energy communities. While energy communities can exist on multiple levels, this use case concentrates on prosumer-centric communities. There shall be no limitation to the size and form of peers in the community.

While the community shall mostly comprise small prosumers (like residential homes) and small business entities (e.g. companies with generators or storage), VPPs, SMEs and local utilities are not excluded if they act as peers with the same rights and obligations. A specific role in the energy community can link it to other such communities and other energy markets. Governance policies and incentive mechanisms like special tariffs or pseudo-currencies will be explored. For the realization of this use case, the Flexibility Trading Platform will be coupled with the P2P market toolbox using Distributed Ledger Technologies.

Complete Narrative

The energy community addressed by this use case has the following assumed attributes:

- It can be defined as a subsystem in the electricity market system in terms of a harmonized electricity market model, which implies the possibility to trade energy and flexibility internal to the community and with its environment.
- It has comprehensive energy supply and consumption orientation, targeting inclusion of all energy vectors and overall system optimum; which implies a high level of “self-consumption”
- It tends to organize itself as a virtual socio-economic system with its own set of objectives and values.

While the energy communities under exploration have a lot of similarities with the Citizen Energy Communities or Renewable Energy Communities as described in Art. 16 of the EC Directive on the Internal Market for Electricity Directive on “Citizen Energy Communities” (EMD) or Art. 22 of the EC Directive on the promotion of the use of energy from renewable sources on “Renewable Energy Communities” (RED) respectively, the use case is not limited to communities that fully comply with those directives or their implementation on member state level.

The main objective of the use case is to provide pilot testing cases for two-level trading of energy flexibilities in closed community markets. To that end it will set up two technical roles:

- Automated (technical) trading platform (ATP)
- Business trading toolbox instantiated according to defined algorithms and the users’ business logic.

Both roles can be implemented with a mixture of cloud and edge computing with central and decentral technologies including Distributed Ledger Technologies (DLT) including open, closed and smart contracts.

The processes carried out in automated trading are the technical unit processes that compose the automated management of flexible energies.The processes played out in business trading are the business and market processes associated with the technical processes. Together they constitute the complete chain of the EbIX defined processes in HrEMS: (structure), plan, trade, operate, measure (validate), settle, bill (account).

The energy community strives for a maximum of self-consumption respectively self-supply inside the community. To that end, a maximum of flexibility needs to be mined, provided or traded between members of the community. Nonetheless a specific role/entity in the community needs to link it to technical roles and/or market entities outside the community. This role will most probably be taken by the “Energy Community Responsible (ESR)”, the “Energy Community Operator” (ECO) or a dedicated Aggregator.

As the logical, technical, organizational and business setup of the use-case does not exclude business actors, a local or regional VPP or utility can well be a peer in the energy community. To that end a DSO or local utility can come on various roles:

- peer in the role of a “big prosumer” bringing generation and consumption in storage devices, trading flexible energies with other peers
- service provider to the community, e.g. operating the technologies for the automated and business trading (maybe taking the role of Market Place Operator while not interfering in the trading processes as such)
- aggregator which combines generation and consumption elements into marketable products and trading them with other energy communities or supra-regional market places

Preconditions and Assumptions

Use case diagram

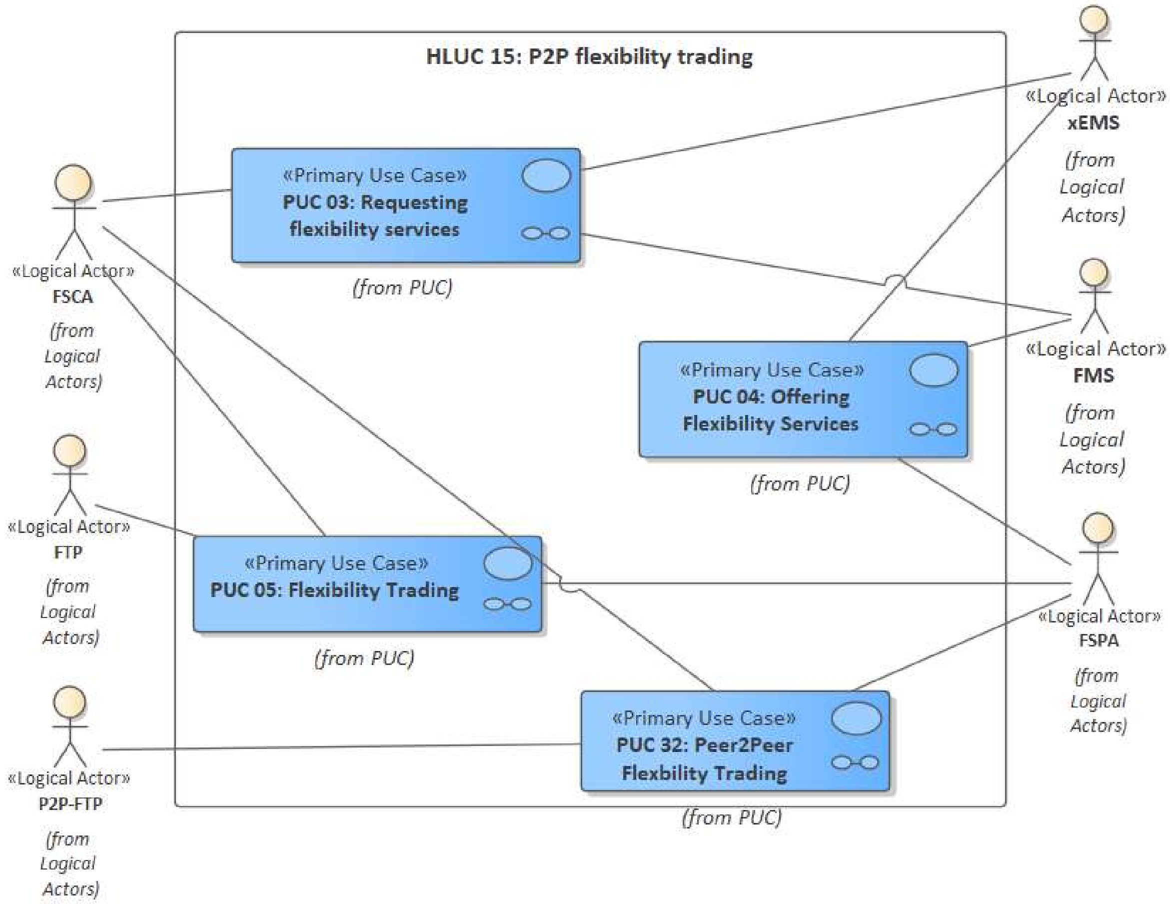

Figure 25: Use case diagram of HLUC 15

3.4.2 Primary Use cases

3.4.2.1 PUC 01: Critical Event Prevention

The Critical Event Prevention (CEP) is the process identifying and mitigating potential violations of the network operational constraints (thermal limits of grid infrastructure and voltage excursions from regulated boundaries) after a power flow analysis performed based on real monitoring and forecasted data.

The violation of the network constraints is identified by the power flow analysis which is performed by the Critical Event Forecaster (CEF) utilizing a Power Flow Simulator (PFS). The grid operational status tracked via the Grid Observability and Monitoring process, the forecasted grid load profile provided by the Energy Forecaster (EF) and the topological characteristics of the distribution grid provided by the GIS are the required inputs for this power flow analysis. The timeframe of the forecasting is defined by the respective one of the congestion management. The results of the power flow analysis (power flows and voltages) are compared with the thermal network limits and the voltage regulated boundaries in order to identify any violation of the network operational constraints.

In the close-to real time situation, SCADA data are used to monitor in real time the levels of voltage and current in the assets of the grid. Values are continuously compared with the network constraints by the CEF. If the measured values get closer to the maximum limits (e.g. 90% of maximum limit) an alarm of critical event in real time is generated.

In case a network operational issue is identified, then a mitigation plan is extracted by the Grid Operation Planner (GOP) considering grid reconfiguration and exploitation of DER flexibility. The grid reconfiguration entails the proper scheduling of the switchgear operational status. In case that network reconfiguration cannot adequately mitigate the network operational issue, flexibility offered by dispatchable assets located in the problematic area can complementarily be exploited for supporting network operation.

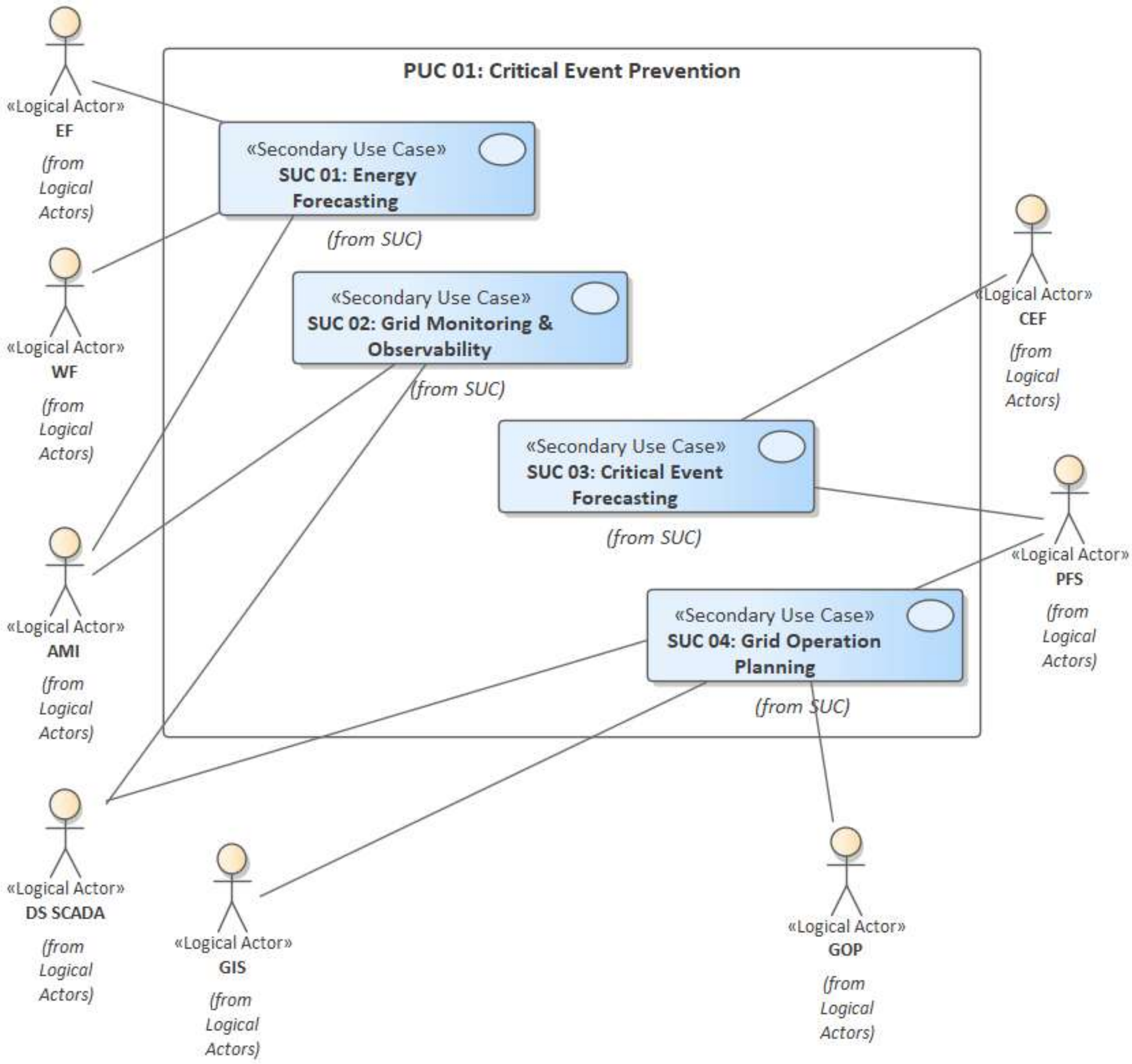

Figure 26: Use case diagram of PUC 01

3.4.2.2 PUC 02: Grid reconfiguration Schedule Dispatching

The grid reconfiguration plan extracted from the power flow analysis of the problematic grid area performed by the GOP dictates the proper modification of the operational status of the switchgear affecting consequently the power flows in the specific area of the distribution grid. The implementation of the grid reconfiguration plan is scheduled by the Switchgear Dispatch Scheduler (SDS). SDS executes the GOP's plan by requesting the successive modification of the status of the respective switchgears from the DS-SCADA. After each request, the status of the modified switchgear is checked by the SDS through DS-SCADA for validation purposes.

3.4.2.3 PUC 03: Requesting flexibility Services

The communication of the flexibility needs of a flexibility service consumer (ex. DSO, BRP, etc.) either directly to the Flexibility Service Providers or the flexibility markets should be realized in a common way. The direct interaction between DSO and Flexibility Service Providers is realized in respect to the rules defined by the bilateral contracts while the respective one between DSO and Market Operator is realized in respect to the market rules. The Flexibility Offering Agent of the DSO (DSO-FOA) is responsible for realizing such interactions.

Flexibility is considered as a five-dimensional vector comprising the amount of energy, the type of energy (active/reactive), the time, the location and the price. The energy dimension provides the increment or the decrement of the active/reactive energy exchanged with the electricity grid. The time dimension provides the time period during which the specific amount of energy consumption/production is requested. The location is the flexibility dimension which set the spatial boundaries of the flexibility needs relatively to the distribution grid. The operational issues in the distribution grid, i.e. congestion, voltage excursions, power quality, etc., have local characteristics rather than systemic ones. In light of this, flexibility which is spatially correlated with the grid problematic area can only be exploited for supporting network operation. The fourth dimension in the flexibility needs vector is optional and defines the upper price threshold for accepting flexibility services. If the price threshold is not defined, then DSO is considered as a "price-taker" accepting flexibility services at any cost. This might be the case when grid is operating under emergency or critical conditions. In other circumstances, ex. reducing network technical losses by exploiting DER flexibility, the cost of consuming flexibility services is bounded above by the price dimension of flexibility.

3.4.2.4 PUC 04: Offering Flexibility Services

The extraction and trading of the flexibility from distributed, dispatchable energy resources are managed by the local Energy Management System (xEMS) and the local Flexibility Service Providing Agent (FSPA) as illustrated in Figure 27. The EMS system is responsible for monitoring and managing the energy assets under its responsibility as well as extracting the potential flexibility that can be offered by the DERs considering DER's operational status and constraints. The FSPA is responsible for managing the potential flexibilities identified by the EMS and defining the bidding strategy in terms of complete or partial selection of potential flexibility to be traded, the temporal and spatial characteristics of the flexibility and the respective activation cost. In cases that the trading risk of distributed resources is high enough due to their dynamic behavior or the market participation of DER units individually is prohibited by the market rules, the individual DER flexibilities can be managed and traded in an aggregated way by the Flexibility Management System (FMS).

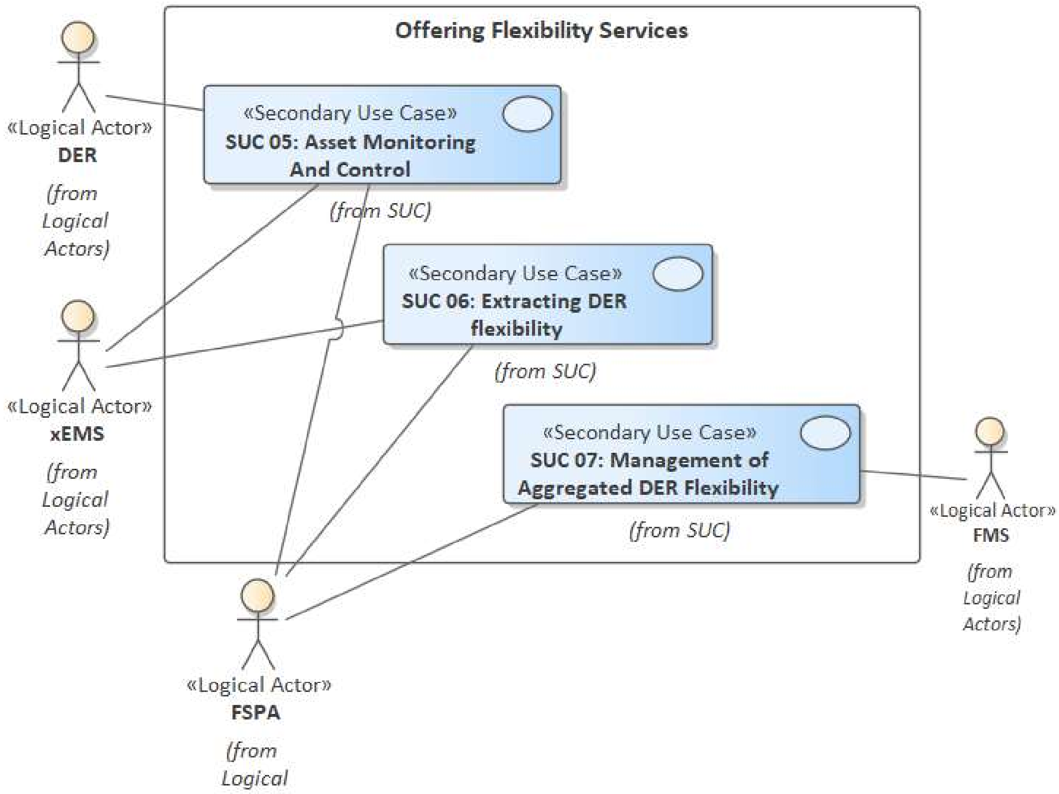

Figure 27: Use case diagram of PUC 04

3.4.2.5 PUC 05: Flexibility Trading

The Flexibility Trading Platform (FTP) is an auctioning mechanism for matching the flexibility requests provided by the flexibility service consumers (i.e. DSO, BRP, etc.) with the flexibility bids offered by the Flexibility Service Providers. The coupling between flexibility request and flexibility offer should be realized in all the dimensions of the flexibility vector: energy, spatial, temporal and price.

The flexibility trading platform can be utilized at different levels of the electricity grid. The FTP can be utilized at prosumer's level for optimal flexibility management and balancing of the local resources, ex. within a microgrid, an energy community, etc. Furthermore, the FTP enables Flexibility Service Providers to optimize their flexibility portfolio for providing flexibility to various energy stakeholder via bilateral contracts. Moreover, FTP can be utilized by BRPs for managing optimally the flexibility lying either inside or outside their area of responsibility for balancing purposes. Finally, the FTP facilitates independent Market Operators to develop local markets for flexibility trading within the distribution domain.

3.4.2.6 PUC 06: Ex-post network performance assessment

The evaluation of the network operational performance after the implementation of the mitigation plan dictated by the different applications of the DSO Toolbox in order to mitigate network operational issues is performed by the Ex-Post Assessment Application (EPAA). The ex post network performance assessment is triggered by the DMS system. Upon triggering, the EPAA retrieves real grid monitoring data from the DS-SCADA system reflecting the current operational status of the distribution grid. This network operational snapshot is forwarded by the EPAA to the Critical Event Forecaster (CEF) in order to perform a power flow analysis utilizing the Power Flow Simulator (PFS) and validate that no operational constraint violations occur after the implementation of the mitigation plan.

3.4.2.7 PUC 07: Voltage compensation via reactive power control

The Voltage Compensation (VC) is the process identifying and mitigating voltage excursions within the distribution grid considering the voltage upper and lower thresholds dictated by Network Codes and international standards, as it is illustrated in Figure 28.

Under/Over voltage issues are identified considering close-to-real time voltage measurements provided by the DSO legacy systems, i.e. DS-SCADA and AMI, as well as local measurement devices named PEDs installed by the battery storage owners at DER level. These voltage measurements are compared with the predefined voltage constraints by the Critical Event Forecaster (CEF). In case that voltage excursions are identified, a mitigation plan is extracted by the Grid Operation Planner (GOP).

The GOP performs a power flow analysis exploiting the Power Flow Simulator (PFS) in order to identify the flexibility needs in terms of reactive power and grid location. The grid operational status provided by the Grid Observability and Monitoring process and the topological characteristics of the distribution grid provided by the GIS are the required inputs for this power flow analysis.

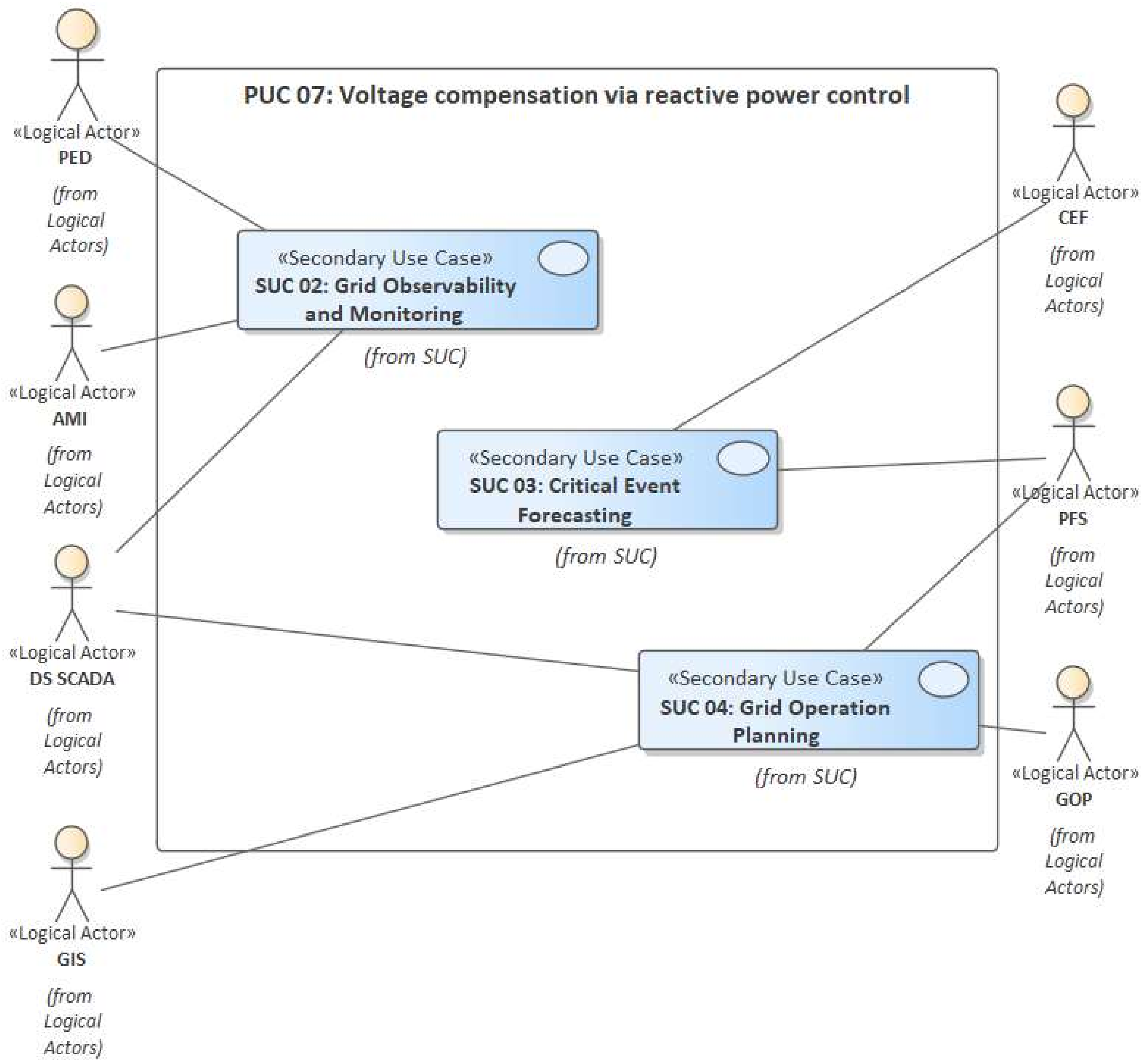

Figure 28: Use case diagram of PUC 07

3.4.2.8 PUC 08: Grid Monitoring and Islanding Detection

The detection of uncontrolled islanding requires the extension of the monitoring capabilities offered by DSO's conventional DS-SCADA enabling the real-time monitoring of grid status at prosumer level. The monitoring data concerning the grid status (i.e. voltage level at substation/feeder level, protection system status, etc.) is retrieved and provided by the DS-SCADA. Real time monitoring data from the PED/DER assets (i.e. voltage level, frequency, etc.) are retrieved and communicated periodically by the PEDs to the IPMA. A data analysis is performed continuously by the IPMA by comparing the grid status data provided by the DS-SCADA and the local grid operational data provided by the PEDs/DERs in order to identify uncontrolled islanding situations.

The sub-processes of the grid monitoring and islanding detection are illustrated in Figure 29.

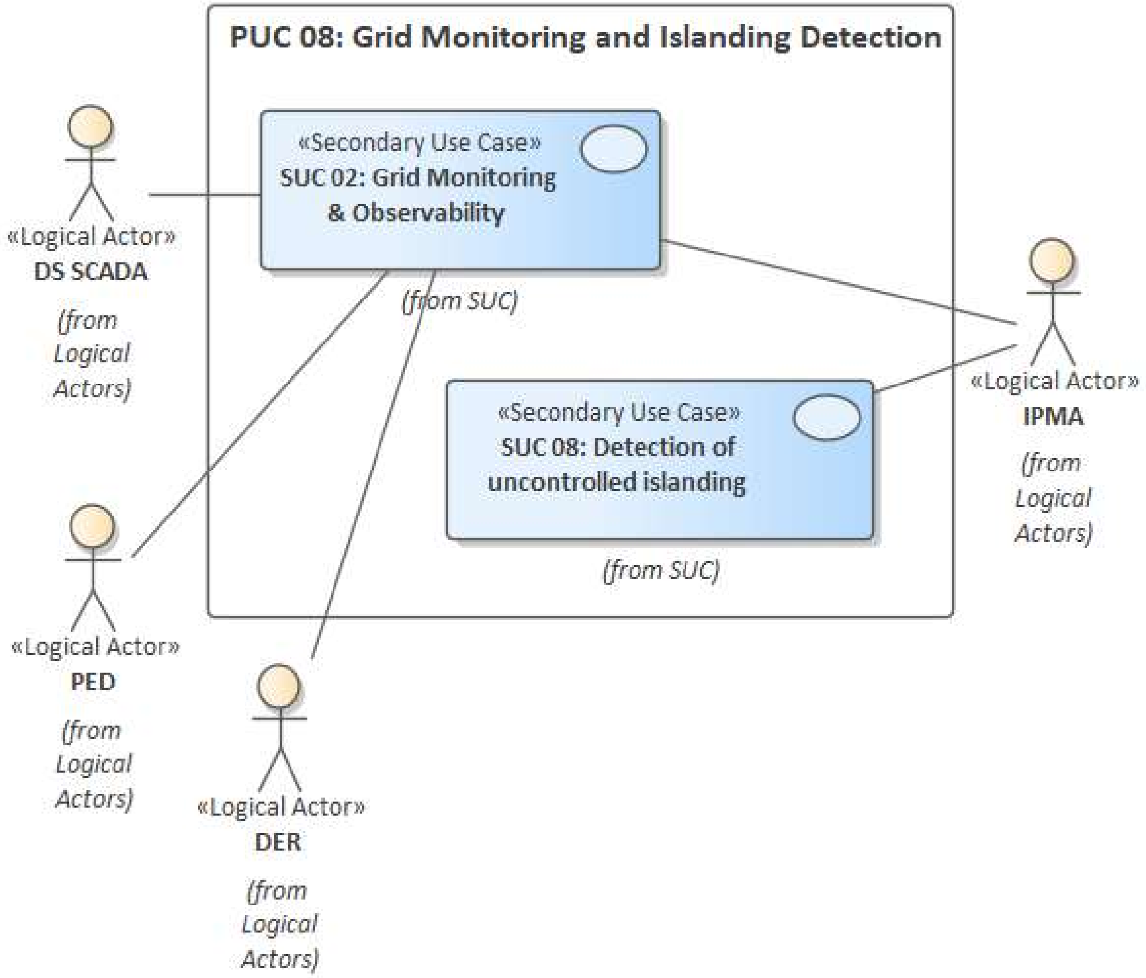

Figure 29: Use case diagram of PUC 08

3.4.2.9 PUC 09: Mitigating uncontrolled islanding

This process refers to the execution of the mitigation plan via the DS-SCADA system upon a detection of uncontrolled islanding events. The mitigation plan comprises of power set-points for each individual PED aiming to introduce perturbations within the islanded grid area or a reconfiguration of the grid. . Such perturbations affect the initial local energy balance provoking the activation of the protection system of the distributed storage assets (DER). The updated field measurements provided by the DERs/PEDs are exploited for evaluation purposes by the IPMA.

3.4.2.10 PUC 10: Grid Monitoring and Power Quality Assessment

The detection of network power quality issues requires the extension of the monitoring capabilities offered by DSO's conventional DS-SCADA, enabling the real-time monitoring of grid status at prosumer or grid zonal level. The monitoring data concerning the grid status is provided by the DS-SCADA and the real time power quality monitoring data from the DER/PED assets provided by the PEDs is processed by the PQS and compared with the power quality standards dictated by the Network Codes and international standards in order to identify potential power quality issues.

The sub-processes of the grid monitoring and islanding detection are illustrated in Figure 30.

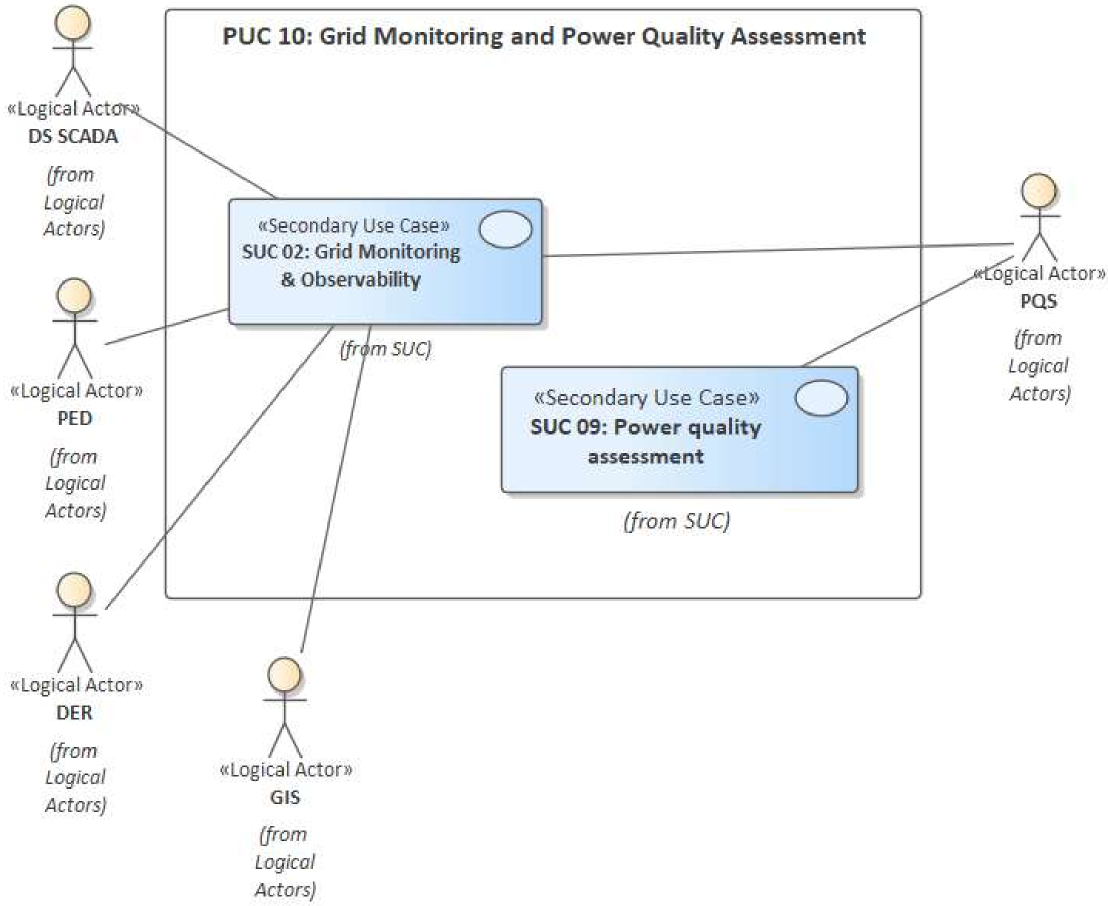

Figure 30: Use case diagram of PUC 10

3.4.2.11 PUC 11: Mitigating network power quality issues

The process for mitigating network quality issues is triggered by the PQS in order to ensure the power quality of the network operation after the power quality assessment phase. Upon being triggered, the PQS calculates the operational set-points of the PEDs based on a three-phase power flow (exploiting PFS) and harmonic analysis of the grid and a deterministic optimization algorithm taking into account the technical specifications/restrictions of the PED/DER assets. Operational power quality set-points defined by the PQS are communicated via the DS-SCADA to the PEDs which are responsible of executing the ordered operational set-points.

3.4.2.12 PUC 12: Self-Healing

Self-healing is the process for identifying network faults and defining a mitigation plan for limiting the boundaries of the faulted grid area and maximizing the number of electrified network users.

Self-healing process after a fault occurs entails initially the detection of the grid fault and its location performed by the Fault Detection Application (FDA). The outcome of this analysis - comprising the fault type, data source, isolated grid area in terms of lines, buses, switchgears, etc.- are communicated to the Grid Operation Planner (GOP) in order to define a grid reconfiguration plan aiming to minimize the faulted grid area and maximizing the number of electrified network users. Since the network topology is modified, the power flows in that area are affected consequently. In light of this, a power flow analysis is performed by the Critical Event Forecaster (CEF) exploiting the Power Flow Simulator (PFS) in order to identify potential grid operational constraint violations, i.e. network congestion, voltage excursions, etc. The timeframe of the forecasting is defined by the estimated duration of the fault. The respective forecasted production/consumption profiles for the time horizon of the power flow analysis are generated by the Energy Forecaster (EF) in respect to the weather forecast provided by the weather forecast agency.

In case that critical network events are forecasted, GOP analyses the potential exploitation of available DER flexibility. The flexibility needs identified by this analysis comprise the requested amount and type of power, the spatial and temporal requirements.

The sub-processes of self-healing process are illustrated in Figure 31.

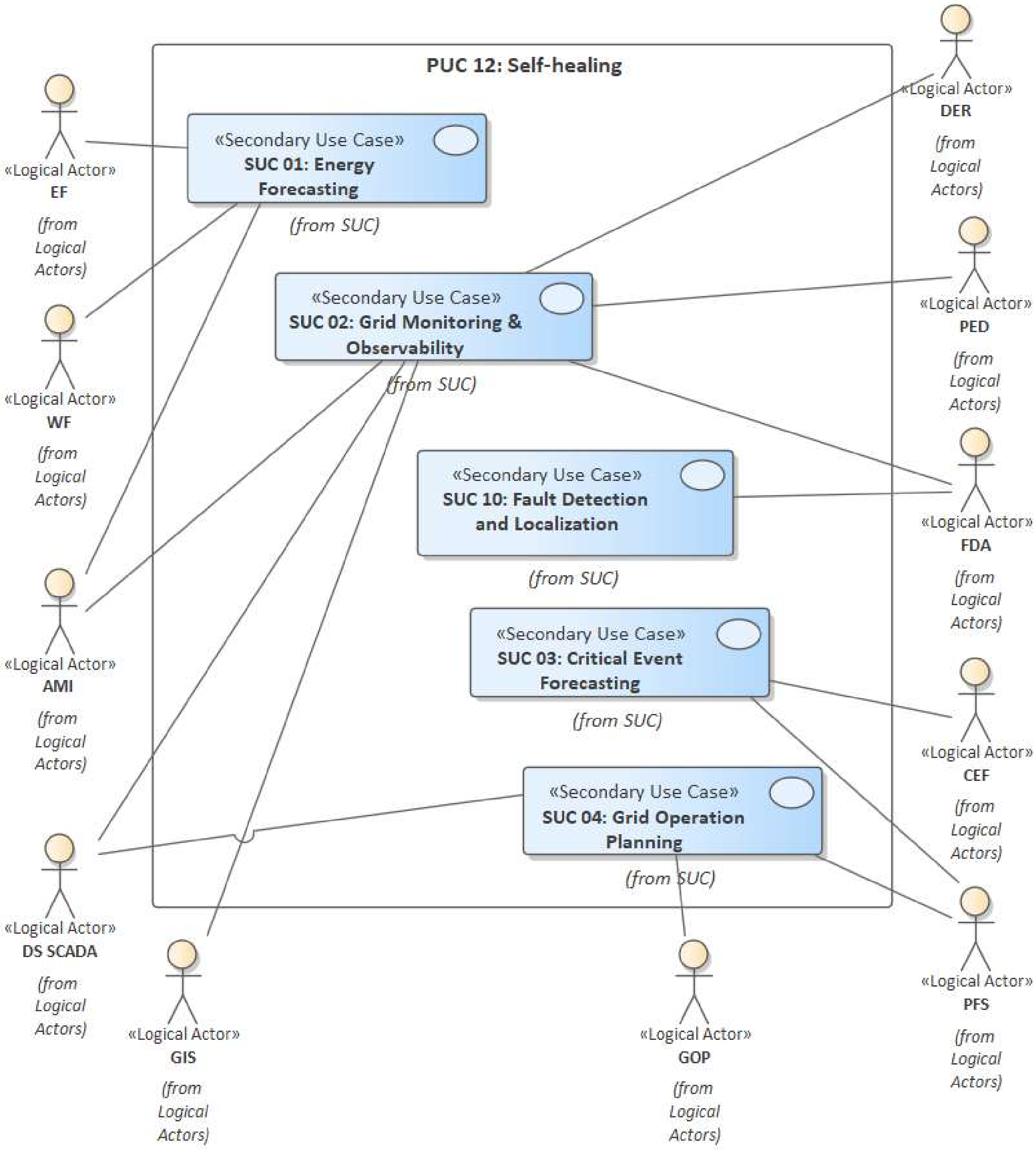

Figure 31: Use case diagram of PUC 12

3.4.2.13 **PUC 13: Minimizing network technical losses**

The minimization of the network losses under high RES share conditions can be achieved by shifting flexible demand preferably from peak network demand hours to time periods when there is excess of RES production. Storage capacities can perfectly serve this objective by increasing the demand during high RES production hours and by injecting energy to the grid during peak demand hours.

This consumption-production matching at a specific grid area (at substation level) during a specific time horizon can be achieved by exploiting the flexibility offered by distributed dispatchable sources (generation/consumption/storage) located at distribution level. The flexibility needs reflecting the generation-consumption unbalances in terms of energy gap, time window and grid location are extracted by the Grid Operation Planner (GOP)

The minimization of the losses within a specific time horizon requires the forecasting of the generation/production profiles for the time period under study. This is realized by the Energy Forecaster (EF) which utilizes forecasted weather data form external weather agencies as well as historical data provided by the AMI and DS-SCADA.

The sub-processes of the network load variance minimization process are illustrated in Figure 32.

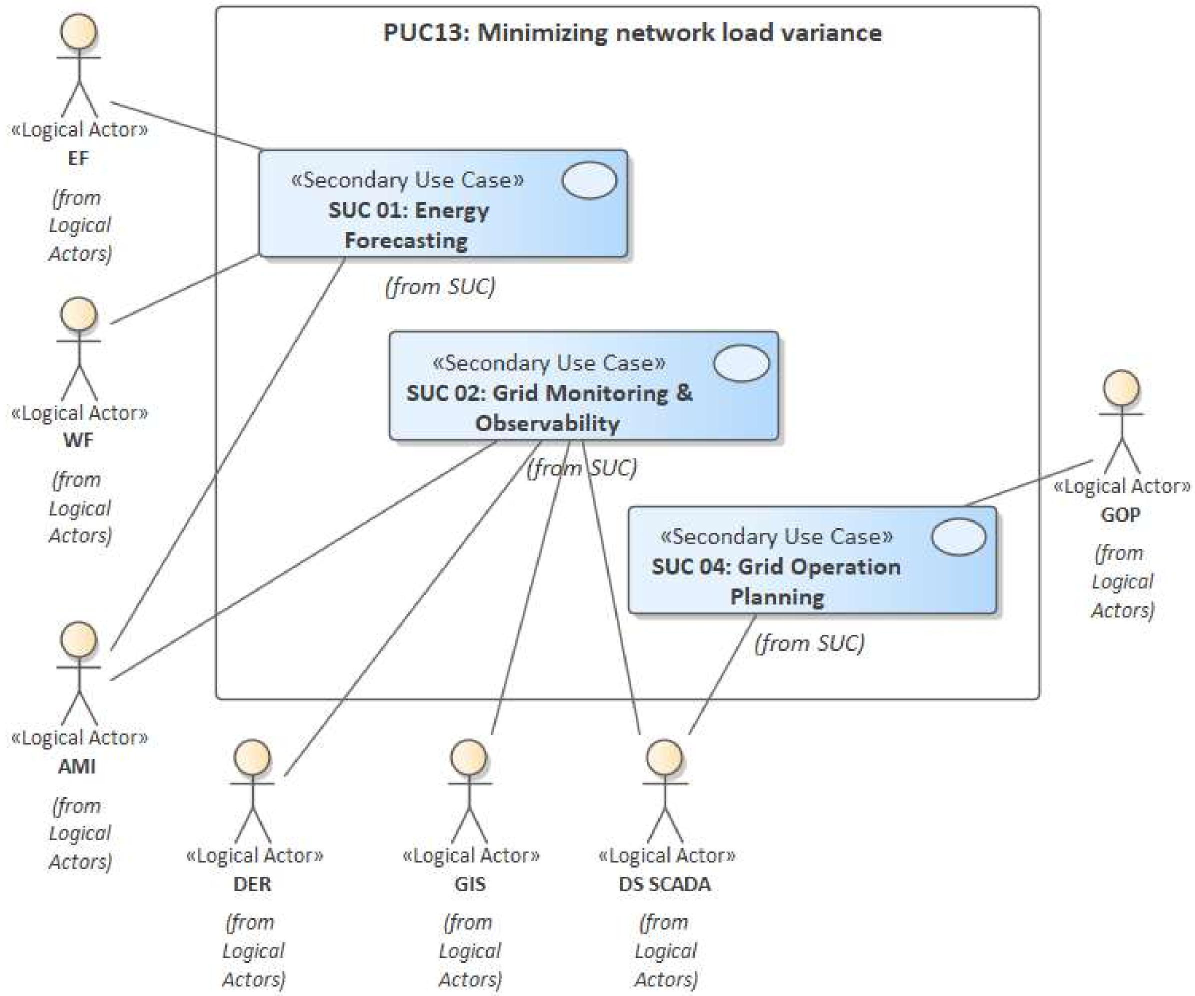

Figure 32: Use case diagram of PUC 13

3.4.2.14 PUC 14: Processing network data

Network data can be provided in different data format. Even though the Common Information Model (CIM) is the standard that enables information exchange about an electrical network in a common, network data is not always adopted or it is adopted partially. The exploitation of heterogeneous network data files by a specific process entails the pre-processing of this data and its conversion to a commonly understandable data format.

3.4.2.15 PUC15: Defining Bidding Strategy

The participation of market related entities to wholesale or balancing markets adheres to the rules and restrictions imposed by the respective market frameworks. The bidding strategy aims to transform the energy needs or available flexibility into bids accepted by the wholesale or balancing markets by constructing the appropriate order types (e.g. Reversible, linked, exclusive groups etc.).

3.4.2.16 PUC16: Disaggregating day-ahead market schedule

The day-ahead market schedule outputs the market schedules for the market participants. These schedules reflect the aggregated consumption/production profiles of the DERs of each BRP or BSP. The disaggregation process aims to decompose the energy market schedule to several profiles reflecting the consumption/production profiles at nodal/area level of distribution grid.

3.4.2.17 PUC 17: Market schedule prequalification

The market schedule prequalification process aims to assess the impact of the market scheduling of DER assets located at distribution level on the operation of the distribution grid. The prequalification is realized through an optimal power flow of the distribution grid considering its topology and its operational constraints. The optimal power flow is performed by the PFS and it requires the outcome of the disaggregated day-ahead market schedule process as well as the technical specifications of the distribution network provided by the DS-SCADA. The optimal power flow can result in a modification of the initial disaggregated market schedule so that the voltage and line flow constraints are not violated. In this way, the stable and secure network operation is considered by the day-ahead market scheduler.

3.4.2.18 PUC 18: Day-ahead market scheduling

The day ahead market scheduling is a centralized wholesale market mechanism enabling the exploitation of the flexibility sitting in both the transmission system & distribution grid. The day-ahead market can be a mandatory pool or power exchange where the market model clears buy and sell orders using marginal pricing.

It is an iterative market clearing solution which facilitates the trading of energy, in order to match supply with demand at day-ahead level, and incorporates grid constraints provided by the TSO & DSO to ensure market schedule feasibility and to improve congestion management.

This market model produces also Locational Marginal Prices at T&D nodes/areas. The Retailers are able to exploit the locational variability of the prices to impose flexible pricing schemes to their customers.

The day-ahead market is operated by an Independent Market Operator (MO).

3.4.2.19 PUC 19: Creating dynamic tariffs

The deployment of distributed renewable resources and distributed flexibility at the distribution level implies that there exists both a need as well as a potential for more intelligently managing flexibility at a high temporal resolution, while also accounting for the local constraints of the distribution system. Capacity-driven network tariffs and time-of-use consumer tariffs which internalize these network tariffs are not tailored for this task, neither in the spatial nor in the temporal dimension. What is sought after is a means of pricing at the distribution level which can potently generate prices with high spatial and temporal resolution.

3.4.2.20 PUC 20: Intra-day active/reactive energy flexibility trading

The intra-day flexibility market mechanism enables the trading of DER energy flexibility after the solution of the Day-Ahead Market and before the real-time market mechanisms. The market products will be the active and reactive energy at specific location and time. The full set of product requirements will be specified along the development of the relevant market tool.

3.4.2.21 PUC 21: Control thermal energy systems

CHP's Flexibility can be provided by changing operation mode from electricity driven mode to heat driven mode and back. If a thermal buffer capacity (storage) exists, electricity driven mode can be operated longer than without buffer. Heat-level in buffer creates further time flexibility. This is the same effect used within electrical storage heating systems (heat capacity reflected in temperature-level in thermal storage creates time windows for non-charging).

3.4.2.22 PUC 22: Control EVs

Flexibility can be provided by changing times of charging (and discharging in batteries with sustainable charging-discharging functionality), as long as the EV battery is charged when the EV is not needed for driving and the driver has enough range left.

3.4.2.23 PUC 23: Control hydrogen-electricity conversion

Storage is provided by electrolysis of water to oxygen and hydrogen, which can both be stored and used independently. Electricity generation is realized by a hydrogen fuel cell (HFC) system. Both processes can be controlled independently, depending on the cost of energy to power the electrolysis and the needed electrical energy flexibility. If waste heat generated by HFC can be used by coupling the system to a thermal energy system, the HFC system can be extended and implemented as a CHP system.

3.4.2.24 PUC 24: Managing flexibility within balancing area

The BRP management system comprises a number of processes from monitoring and control of the DER assets belonging to the balancing group up to the trading and clearance of flexibilities. The internal balancing process has been thoroughly presented in HLUC 13.

3.4.2.25 PUC 25: Real-time trading of balancing energy & reserve capacity flexibility

The real-time balancing market is an integrated balancing / congestion management platform that is used for computing DLMPs and real-time balancing actions. The market is operated by an independent Market Operator who collects all the flexibility offers in both transmission and distribution grid along with imbalances runs the real-time market platform which determines upward and downward activations of real and reactive power.

The goal of the real-time market platform is to integrate congestion management and balancing throughout the transmission and distribution system. The resulting price signals provide locational investment signals that attract investment in needed technologies, as well as signals for reinforcing the network wherever this is required. Moreover, the platform promotes economic efficiency by matching orders that benefit from trade, and by coordinating the operations of balancing and congestion management. Finally, the produced DLMPs prevent market manipulation through INC-DEC gaming by exposing agents to a locally uniform price signal and overcoming the well-known manipulation opportunities that result from zonal pricing.

As it holds for every electricity markets, the participation in and the operation of the real time balancing market adhere to specific principles and rules. More specifically, the following rules are considered:

- The envisioned timeline is based on that of MARI (tertiary reserve platform).
- Bidding strategies unveiling: bids are submitted a few minutes prior to real time (e.g. up to 30 minutes prior to the relevant balancing interval). Bids can follow the typical format of EUPHEMIA (e.g. simple curves, interpolated orders, or more complex block orders).
- The platform runs for 1-5 minutes.
- The resulting prices are recorded in a database, and dispatch instructions are communicated to Flexibility Service Providers, who need to react within their full activation time (eg 12.5 minutes).
- Deviations are settled ex post based on the recorded prices using the uniform prices (DLMPs) that are generated by the platform.

Participation in the platform is obligatory for Flexibility Service Providers (i.e. BSPs) who have sold reserve capacity in forward (ex. day-ahead auctions). Participation is optional for all other entities (ex. free bids). The platform offers a value stream for flexible resources, but bidding is not mandatory if resources have not committed to offer reserve / flexibility to the DSO or TSO. Thus, for example, bilateral trades can override the platform by being directly submitted as price-inelastic bids into the platform, and do not incur any excess charge or payment if they follow their bilateral schedule.

3.4.2.26 PUC 26: Integrating flexibility from energy communities

This primary use case aims to integrate the available flexibility that is extracted after the internal energy management of an energy community for balancing purposes within the balancing group the energy community belongs to.

The optimal management among the members of the energy community is realized in a peer-to-peer trading approach which is analyzed and implemented within HLUC 15 “P2P flexibility trading”. The flexibility surplus which remains idle after the local optimal management can be externalized and offered for the balancing needs of the respective banging group. The flexibility management system of the energy community is responsible for this task.

In the balancing trading of a balancing group, the energy community is represented as a single entity by the energy community responsible.

3.4.2.27 PUC 27: Managing BRP's portfolio

According to the Harmonized Electricity Market Role Model4, the BRP is the party that has a contract proving financial security and identifying balance responsibility with the Imbalance Settlement Responsible of the Scheduling Area entitling the party to operate in the market.

The meaning of the word “balance” in this context signifies that the quantity contracted to provide or to consume must be equal to the quantity really provided by or consumed within its balancing group. In case of imbalances, the energy gap between the market-agreed energy profile and the real can be adjusted by the BRP either via intra-day or balancing markets.

In Fever project, the potentials from the exploitation of the flexibility offered by the balancing group is the main scope. Given that the exploitation of the balancing group’s flexibility is more cost efficient solution than the other market alternatives, the development of the respective flexibility market mechanisms enabling the flexibility trading within the balancing area is necessary.

The BRP’s management system should be enhanced with a trading mechanism which matches the flexibility needs of the BRP with the flexibility bids offered by the dispatchable consumption/production assets owned by the members of its balancing group. In a more optimistic scenario, flexibilities from non-balancing group members can also be accepted in the BRP’s trading process.

3.4.2.28 PUC 28: Microgrid Islanding Detection

The islanded operation of the microgrid is triggered upon the disconnection of the microgrid from the electricity grid at the Point of Common Coupling (PCC). This islanded detection can be realized in two ways: i) Microgrid Operator (MgO) detects the islanding event with the aid of measurements acquired from the PCC and activates the islanding operation mode based on the bilateral agreement with the DSO and ii) MgO does not acquire any measurements and when the loss-of-mains occurs, DSO sends a request to the MgO to trigger the islanding operation mode.

The microgrid islanding detection process will not be developed within the FEVER project. An external triggering event will emulate the islanded detection of the microgrid.

3.4.2.29 PUC 29: Managing optimally microgrid’s flexibility

The Microgrid Flexibility Management System (MgFMS) is responsible for managing and scheduling the operation of the microgrid either in interconnected or islanded operation mode. In case of interconnected microgrid operation, the flexibility offered by the distributed dispatchable units are exploited for minimizing the overall operational cost of the microgrid and maximizing revenues from the provision of flexibilities services to DSOs. In case of islanded microgrid operation, the MgFMS exploits local DER flexibility for maintaining voltage and frequency within acceptable limits and supporting partially or completely the local consumption needs in prioritized order.

Based on the spatial short-term load and generation forecasting provided by the Energy Forecaster (EF) in respect to weather forecasts from an external weather forecast agency, MgFMS develops a local multi-objective optimization strategy and informs the prosumers within the microgrid context to trade their flexibility. The extraction and trading of the flexibility capacities from distributed, dispatchable energy

[4] Available online at https://www.entsoe.eu/digital/cim/role-models/

resources (DER) are managed by the Microgrid Management System (Microgrid EMS) and the local Flexibility Service Provider Agent (FSPA).

The sub-processes of the optimal management of microgrid's flexibility are illustrated in Figure 33.

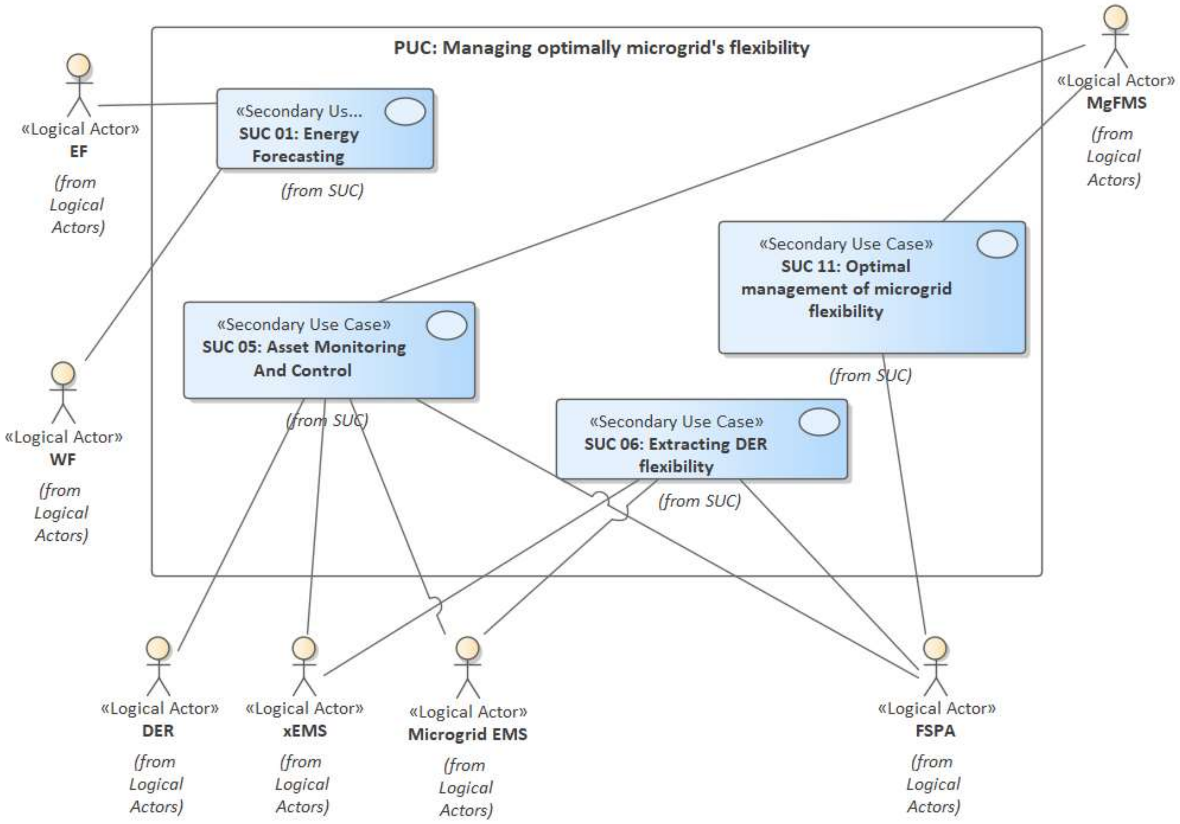

Figure 33: Use case diagram of PUC 31

3.4.2.30 PUC 30: Remunerating flexibility service provision

When flexibility service provision is forced by a FSCA, who is not directly contracted with FSPA, he needs to provide remuneration payment to FSPA. This agreement is part of the dynamic tariff, where the dynamic pricing structure is put on record.

3.4.2.31 PUC 31: Participating in regional flexibility markets

The participation of the BRPs in the regional flexibility market requires the extraction of their flexibility needs or surplus in respect to the available DER flexibilities within their balancing group. This process receives as input the outcomes of the BRP's portfolio management and communicates the balancing needs or the flexibility surplus to the regional flexibility trading platform. This interaction adheres to the rules and restriction that the regional flexibility market imposes.

3.4.2.32 PUC 32: Peer2peer flexibility trading

The peer-to-peer flexibility trading platform is a platform for providing the environment to directly trade flexibility requests provided by the flexibility service consumers (i.e. prosumer peer) with the flexibility bids offered by the Flexibility Service Providers (i.e. consumer peer). The coupling between flexibility request and flexibility offer should be realised in all the dimensions of the flexibility vector: energy, spatial, temporal and price. The contracting and billing will be realized by Distributed Ledger Technologies.

The p2p flexibility trading platform can be utilised at different levels of the electricity grid. The P2P-FTP can be utilised at prosumer's level for optimal flexibility management and balancing of the local resources, in particular when they form a socio-economic system with its set of values and objectives, ex. within a microgrid, an energy community, etc. Furthermore, the P2P-FTP enables Flexibility Service Providers to optimize their flexibility portfolio for providing flexibility to various energy stakeholder. Moreover, P2P-FTP can be utilized by BRPs for managing optimally the flexibility lying either inside or outside their area of responsibility for balancing purposes. Finally, the P2P-FTP facilitates independent Market Operators to develop local markets for flexibility trading within the distribution domain.

3.4.3 Secondary Use cases

3.4.3.1 SUC 01: Energy Forecasting

The Energy Forecaster (EF) provides forecasted consumption or production profiles in respect to the three dimensional request: the pin-point of the grid where forecasting is needed, the specific forecast time horizon (short terms, day-ahead, etc.) and the forecast granularity (15 minutes, hourly, day-ahead, etc). The forecast granularity is highly dependent on the resolution of the input data provided by smart meters. The application consuming the energy forecasting service is responsible for providing the appropriate historical input data as well as the weather forecasts retrieved by an external weather forecasting agency to the EF for extracting the consumption/production forecasts.

3.4.3.2 SUC 02: Grid Observability and Monitoring

From the DMS it is always possible to monitor the state of the grid by means of data collection from systems such as SCADA, PQM and AMI. Complementary to the conventional DSO's legacy systems, the grid monitoring can be enhanced by the acquisition of field measurement data at prosumer level for grid operation purposes, i.e. power quality measurements, voltages, etc. This will be realized through the implementation of PEDs connected either at network feeder level and/or at DER asset level and communicating field measurements (i.e. voltage, current, harmonics, frequency, etc) to the DSO. The sampling and the transmission frequency is case dependent (i.e. fault detection, grid power quality monitoring etc.)

3.4.3.3 SUC 03: Critical Event Forecasting

The Critical Event Forecaster is responsible for performing power flow analysis for evaluating network operation and identifying critical event conditions in the distribution grid. The CEF can be triggered by another actor or it might be automatically executed periodically.

This power flow analysis may refer either to the operational phase or the planning one depending the use case. In operational phase, the identification of critical network events is based on real measurement data retrieved by the grid observability and monitoring process. In planning phase, the power flow analysis is performed based on forecasted production/consumption profiles of the network busses provided by the Energy Forecaster.

The power flow performed by the Power Flow Simulator (PFS) outputs the dynamic electrical grid parameters i.e. line flows and bus voltages. These values are compared by the CEF with the technical or regulated constraints in order to identify (potential) critical network events in terms of location, type, duration, etc.

3.4.3.4 SUC 04: Grid Operation Planning

The Grid Operational Planner (GOP) provides an optimal scheduling of the distribution network operation in order to mitigate a network operational issue identified by the critical event forecasting analysis under normal/emergency grid conditions or to enhance the network operational efficiency in terms of minimizing technical losses. Different scenarios are identified, according to the objective of each case:

- Grid operation planning to avoid critical event: in this scenario the GOP schedules grid operation pursuing the objective of avoiding critical events, thus congestion and under/overvoltage issues;
- Grid operation scheduling to reduce power line losses: in this scenario the GOP schedules grid operation pursuing the objective of reducing power line losses, thus inducing local consumption of the locally generated electricity;

- Grid operation scheduling to isolate the fault and reduce the impact on the customers' supply: in this scenario the GOP schedules grid operation with the objective of bypassing the fault and allow continuity of supply.

The optimal scheduling of the GOP comprises two components: the network reconfiguration schedule and the energy flexibility needs which can be potentially provided by the DERs associated with the problematic grid area. The network reconfiguration is realized by the modification of the switchgear’s status which affects the power flows in the distribution grid. In case of emergency conditions, the grid reconfiguration aims to isolate the faulted grid area and maximize the electrified one. DER flexibility exploitation is a complementary action to grid reconfiguration and is required when the latter either cannot adequately fulfil GOP’s objective or provokes new grid operational issues. The definition of the DER flexibility needs by the GOP comprises three components, the amount of active/reactive energy consumption/production required and the spatial as well as temporal characteristics of the flexibility.

The optimal scheduling analysis might be requested either during the operation phase where the current network topology defined by the switchgear status and the current grid measurements from the GIS and DS-SCADA systems or during the planning phase where forecasted production/consumption grid profiles should be provided.

3.4.3.5 SUC 05: Asset Monitoring and Control

The provision of flexibility from a DER asset requires monitoring and control capabilities. Such capabilities can be partially or completely offered by the power electronic interfaces of the DERs. Access to that capabilities can realized either directly (ex. Modbus communication) or via web interfaces. In case that additional monitoring or control capabilities are needed for project purposes, these will be realized by the implementation of additional hardware and software i.e. DER Flexibility Service Provider Agents (FSPA) and Energy Management Systems (EMS).

3.4.3.6 SUC 06: Extracting DER flexibility

The current operational status of a flexible DER along with its operational restrictions are necessary for identifying the flexibility that can potentially be offered by a DER asset. The intelligence required for identifying the potential flexibility of DER assets is provided by the EMS and/or the FSPA.

The strategic management of the potential flexibility offered by DERs in order to be traded is decided by the FSPA. The FSPA is responsible for defining the five dimension of a flexibility bid vector required for trading: increase/decrease of energy consumption/production, type of energy (i.e. active/reactive) temporal dimension providing the time production/consumption profile fulfilling the energy needs, the spatial dimension reflecting the grid location of the DER within a distribution network and the financial dimension reflecting the profit for offering flexibility or the cost for purchasing it.

3.4.3.7 SUC 07: Management of Aggregated DER Flexibility

In cases that the trading risk of distributed resources is high enough due to their dynamic behavior or the market participation of DER units individually is prohibited by the market rules, the individual DER flexibilities can be managed and traded in an aggregated way by the Flexibility Management System (FMS).

The flexibility offers extracted by the FSPA for the DERs under responsibility are forwarded to the FMS which is responsible for aggregating the flexibility vectors (energy, time, location and price) and extracting a single flexibility bidding profile. In case of flexibility activation request the reverse process holds, i.e. disaggregation of the single flexibility profile to individual flexibility profiles to be forwarded to the FSPAs, respectively.

3.4.3.8 SUC 08: Detection of uncontrolled islanding

The IPMA assesses the overall grid conditions (emergency, alert or normal operation) by comparing the grid monitoring data provided by the DS-SCADA and the field measurements by the PEDs. This comparative analysis aims to identify the situation in which an island is created unintentionally, without the possibility to operate it, and the passive anti-islanding protections of DER inverters do not detect and interrupt the island due to their Non-Detection Zone (NDZ[5]). The detection of uninterrupted islands is continuous and requires the implementation of advanced algorithms, ex. graph theory, state estimation, etc.

3.4.3.9 SUC 09: Power quality assessment

The PQS analyses the measurements collected by the DS SCADA and PEDs and combines them with the topological configuration of the grid in order to provide a feedback about the grid status. If the electrical parameters of the grid status violates the quality standards dictated by the national grid codes and/or international standards, the process for mitigating network power quality issues is triggered by the PQS.

3.4.3.10 SUC 10: Fault detection and localization

The Fault Detection Application (FDA) is responsible for detecting faults by analyzing the monitoring data provided by the DS-SCADA and AMI and comparing it with the predefined operational boundaries of the normal grid conditions. The data process analysis is executed periodically either in automatic or manual mode. Different approaches and algorithms can be applied to fault detection. The basic methods can be classified as: impedance-based, travelling wave, and pattern recognition.

This process will not be developed within the framework of FEVER project.

3.4.3.11 SUC 11: Optimal management of microgrid's flexibility

The micro-grid comprises a set of aggregated prosumers able to respond effectively to flexibility calls by leveraging the owned flexible DERs such as PV generation, energy storage systems and flexible loads. This capability can satisfy a wide range of objectives of economic, technical or environmental nature.

One of the main objectives of the micro-grid operator (MgO) when participating in the flexibility market is to minimize expenditure and maximize flexibility trading associated revenue, while ensuring that all systems are functional and there are no noticeable inconveniences. Of course RES maximum penetration or lower carbon emissions can be complementary objectives. In addition, optimal exploitation of the flexibility assets can benefit the microgrid's smooth operation even under islanding conditions by ensuring power supply continuity to critical loads and maximizing the contribution of RES (i.e. PV systems).

[5] Passive anti-islanding methods monitor selected parameters, such as voltage, frequency or their characteristics, and they switch off the inverter if one of these parameters deviates outside specified boundaries or conditions. The boundary limits of these parameters define the non-detection zone (NDZ).

4. Discussion

This document aims to identify a set of business and technical use cases that leverage flexibility from dispatchable DERs located in the distribution grid as well as the provision of market and grid-oriented flexibility services.

Initially, the list of business actors to benefit from the FEVER solutions and services as well as their business objectives were identified. Distribution System Operators, Market Operators and Flexibility Service Providers (either as individual flexible prosumers or as Flexibility Aggregators), are the key business actors facilitating higher RES deployment levels at distribution level, while ensuring the secure and reliable network operation.

The processes and the technical actors were analyzed in detail in this document, outlining the operational boundaries of the FEVER HLUCs as well as the respective preconditions/assumptions towards their realization. The definition of the processes and the technical actors reveals the needs for solutions/services that will be eventually introduced by or enhanced within the FEVER project.

Overall, the FEVER project aims to respond to the concerns raised by the E.DSO [DSOF] with regards to the procurement of flexibility, as summarized in the following points.

DSOs should be allowed to procure flexibility services in all timescales in addition to traditional grid reinforcement.

FEVER approach: The procurement of flexibility services towards network support is considered in different timeframes from planning down to operational one:

- Seasonal planning: to avoid congestion/voltage issues deriving from a significant demand variation due to the change of people's habits in the different seasons (e.g. a vacations village that gets full of tourists only some months per year)
- Day-ahead planning: periodic daily forecasting of consumption/generation (using smart meter data) to foresee possible grid issues during the following day and prevent them by planning the operation of the grid.
- Close-to real time planning: monitoring of the saturation levels of grid equipment through DSO real time monitoring system, and consequent planning of preventing action, if the levels are close to the maximum limit. Furthermore, in case of emergency operational conditions, i.e. network faults, grid and DER flexibility are exploited for minimizing the faulted gird area and maximizing the electrified number of end-users.

The FEVER HLUCs 01-08 tackle the grid-oriented flexibility procurement in different timescales.

DSOs should be able to decide which situations call for a market based solution and which situations call for grid development, while maintaining a high quality of service.

FEVER approach: DSO is responsible for operating, maintaining and developing the distribution network in the most cost-efficient way in order to ensure the required network capacity for serving the consumption. Maintaining the secure and reliable network operation may require the reinforcement and extension of distribution networks which is not always the most efficient and cost viable solution. The solutions and services enabling the exploitation of DER flexibility by DSOs to complement grid reinforcement towards grid operational support is a key project objective. A cost benefit analysis extracting the financial benefits of leveraging a market based flexibility solution in comparison to grid reinforcement is highly case-dependent and it is out of the scope of this project.

System flexibility services are complementary to traditional grid reinforcement. New regulatory frameworks should include mechanisms that both allow DSOs to procure system flexibility services and to recover their cost, also taking into account the shift from CAPEX to OPEX that system

flexibility services will trigger.

FEVER approach: The regulatory framework is the key factor for the deployment of new flexibility procurement mechanisms. The regulatory framework analysis is not within the scope of this deliverable. The detailed market analysis performed in FEVER's deliverable *D4.1 "Flexibility-related European electricity markets: Modus operandi, proposed adaptations and extensions and metrics definition"* introduces different business models, describing the coordination mechanisms that enable DSOs to access flexibility (i.e. rules-based approach, network tariffs, connection agreements and market-based). All the different models are considered and the ones serving optimally the respective business objectives are adopted within each HLUC presented here, considering in parallel the national policies and regulatory framework.

Besides being able to procure system flexibility services, DSOs should be allowed to act as neutral market facilitators for other new emerging market based services.

FEVER approach: One of the project objectives is to provide the market mechanisms that enable flexibility services exploitation at distribution level. The responsible party for operating and maintaining the platforms / systems implementing such mechanisms is the [Generic] Market Operator. This role can be realized by different actors, depending on the examined use case as well as the national regulatory framework and Network Codes. Thus, under specific conditions, DSOs can exploit FEVER market solutions to act as neutral market facilitators for emerging market-based services. The FEVER flexibility market mechanisms ensure neutrality of flexibility service exploitation. In many cases DER flexibility capacities are exposed to the market as aggregated bids irrespectively of the source asset (battery storage, dispatchable load, CHP, electric vehicle, etc.). The DER participation in different flexibility markets, either via FlexOffers [GEFO] for local markets or appropriate order types for wholesale and balancing markets, enables the neutral market flexibility procurement at financial level. Furthermore, the dynamic pricing mechanisms introduced in HLUC 11:" Creating dynamic tariffs based on flexibility use in the actual regulatory framework" enables the remuneration of the DER flexibility considering its real grid impact by generating prices with high spatial and temporal resolution.

For congestion management, DSOs should have the right to use system flexibility services from distributed generation and load in order to solve grid constraints. However, if there are too few suppliers of system flexibility services in an area, the DSO should have the possibility to conclude individual contacts with customers.

FEVER approach: The HLUC 01 "Advanced network congestion management considering DER & grid flexibility (seasonal, day-ahead, etc.)" aims to provide the monitoring and management solutions and services for preventing network overloading. The flexibility trading solution developed within FEVER project aims to facilitate the flexibility procurement by the DSOs either via bilateral contracts or via third-party flexibility markets.

Safeguards should be built to avoid "gaming" by market players: deliberate creation of a peak in an area to sell system flexibility services to network operators at a high price.

FEVER approach: The innovative day-ahead market mechanism introduced in HLUC 09 "Day-ahead market mechanisms incentivizing energy flexibility trading for mitigating problems of the transmission system & distribution network, integrating wholesale and retail markets" aims to extract the most economical viable market schedules which are feasible in terms of transmission and distribution operational constraints. This is ensured by the prequalification phase of the day-ahead market process where the financially optimal market schedules might be modified ensuring that distribution network is operated in secure and reliable way.

Clear price signals, indicating the real demand for system flexibility services, are needed for the

development of flexibility markets.

FEVER approach: The HLUC 12: “Creating dynamic tariffs based on flexibility use in the actual regulatory framework” implements an advanced dynamic pricing mechanism for the procurement of flexibility in the congestion and overload states of the grid and remuneration for costs of extraction of flexibilities in the scope of equivalent or actual sequential operational close down of DER at distribution level. Capacity-driven network tariffs and time-of-use consumer tariffs which internalize these network tariffs are not tailored for this task, neither in the spatial nor in the temporal dimension. The scope of this use case is to define pricing mechanisms at the distribution level which can pot generate prices with high spatial and temporal resolution.

Communication standards are needed for a secure exchange of data between DSOs and flexibility providers, as well as between the DSO and the TSO.

FEVER approach: In FEVER project the interaction among Flexibility Service Providers, flexibility service consumers and flexibility Market Operators will be realized adopting the FlexOffer [GEFO] communication protocol which was also successfully implemented and demonstrated in several collaborative EU co-funded projects (e.g. GoFlex project).

The development of DER is heavily impacting low and medium voltage networks, requiring a high level of control over the (electricity supply) service level parameters, particularly through the use of advanced sensors and metering data. Monitoring networks and making timely use of available meter data is essential for DSOs.

FEVER approach: From the DMS it is always possible to monitor the state of the grid by means of data collection from systems such as SCADA, PQM and AMI. Complementary to the conventional DSO’s legacy systems, FEVER aims to provide the technologies and services which enhance the grid monitoring by the acquisition of field measurement data at prosumer level for grid operation purposes, i.e. power quality measurements, voltages, etc. This will be realized through the implementation of PEDs at DER assets capable of monitoring and communicating field measurements (i.e. voltage, current, harmonics, frequency, etc.) to the DSO. The sampling and the transmission frequency is case dependent (i.e. fault detection, grid power quality monitoring etc.). Indicative examples are HLUC 03: “Real time detection of uncontrolled islanding by leveraging storage flexibility” & HLUC 07: “Improving power quality and reducing losses through power electronics”.

Demand-side flexibility is based on the assumption that consumers are willing to engage in demand-response activities. Engaging consumers will require incentives and technologies for demand-side flexibility to work and deliver its full benefits. Appropriate incentives should be set up, such as, dynamic tariffs or incentive based demand response in order for the consumer to make savings by offering controllable loads to network operators.

FEVER approach: In FEVER project, the provision of flexibility services from DER assets is realized by the local Energy Management System and the Flexibility Service Providing Agent. The latter one is developed within the FEVER project and it is responsible for managing the potential flexibility extracted by the EMS in order to define the optimal bidding strategy for the DER asset’s market participation towards maximizing the DER owner’s profits and revenues. Indicative examples providing insights on the technologies and services implemented for the DER flexibility provision are HLUC 08: “Economically optimized flexibility leveraging for a grid-connected microgrid” and HLUC 13: “Improving the outcome in flexibility by introducing sector coupling”.

A revision of grid tariffs with, time-dependent and site-dependent components or incentive based demand response, is an essential step towards realizing the benefits, as well as for passing on the costs of flexibility.

FEVER approach: The increasing penetration of renewable DERs can be beneficial in relation to the objectives of participating prosumers and consumers on fair shares. One possible tool for a fair participation could be a dynamic tariff-approach, taking into consideration the inputs of all the local players according to the specific and individual technology and readiness levels in combination with the type and size of their respective participation and allowance. The HLUC 12: “Creating dynamic tariffs based on flexibility use in the actual regulatory framework” introduces and implements an advanced dynamic tariff mechanism for the procurement of flexibility at distribution level. Capacity-driven network tariffs and time-of-use consumer tariffs which internalize these network tariffs are not tailored for this task, neither in the spatial nor in the temporal dimension. The target here is the pricing at the distribution level which can potently generate prices with high spatial and temporal resolution.

A mechanism incentivizing distributed generators to adapt power output based on network use is necessary to enable a more efficient use of the existing distribution assets and deferral of grid reinforcement.

FEVER approach: Two flexibility mechanisms are considered for the flexibility remuneration: i) bilateral contracts and ii) flexibility markets. The HLUCs 01-08 focus on the flexibility procurement for increasing distribution network operational efficiency and deferring grid investments. Bilateral contracts are pre-defined flexibility agreements engaging DER owners to provide flexibility at a predefined remuneration cost whenever it is requested by the DSO for supporting network operation. They are adequately defined so as to contain all the details (e.g. flexibility capacity, spatial indication of DERs relevant to electricity grid, etc.) for activating the flexibility in every situation requested by the DSO. Flexibility markets create a competitive environment where DER flexibilities are traded in financial terms. The flexibility trading bids are defined dynamically based on DER’s operational and electricity market conditions. In both alternatives, the owners of flexible distribution generators will have financial benefits from the provision of grid-oriented flexibility services.

Even if forecasting methods for variable energy generation are quite reliable when considering a large area (such as a country), these techniques lack the necessary accuracy to predict local energy patterns on day-ahead and intra-day timeframes. New smart prediction or other contingency tools will be needed in distribution management systems.

FEVER approach: Advanced regionalized long-term (day-ahead) and short-term (hour-ahead) photovoltaic (PV) power generation forecasting models can achieve accurate hour and day-ahead forecasts for point and aggregated sites (6% to 9%, defining as error the Root Mean Square Error normalized to the nominal capacity of the system). Those approaches are based on data-driven machine learning algorithms, utilizing mesoscale Numerical Weather Prediction (NWP) forecasts, (global horizontal irradiance, ambient temperature, etc.) that are operating at an upscaling level to yield as output the regional PV power forecasts. The models are trained with the aid of data acquired from large scale PV plants which contribute to a significant share within the region. In parallel, Global Horizontal Irradiance (GHI) data are properly manipulated (i.e. angle (α) and azimuth angle (φs) of the sun) and fed to the forecasting model as inputs. The final phase that yields the regional hour and day-ahead PV power forecasting includes a machine-learning algorithm. The latter is trained using the actual data of the reference PV systems each located within the aggregation areas. For the remaining PV systems within each aggregation area (with no actual data), the respective techno-physical parameters are passed to a mathematical learning model that provides the power output for each system. The power output of both models is aggregated per area to provide the regional hour and day-ahead forecasts.

5. List of references

[EFFC] IEA, "CO2 emissions from fuel Combustion",

[CRTB] CIGRE Technical Brochure 586, WG C6-24, conv. S. Papathanasiou, "Capacity of Distribution Feeders for Hosting Distributed Energy Resources," 2014.

[IEVG] N. Hatziargyriou, J. A. Pecas Lopes, E. T. Bower, K. Strunz, M. Rivier, V. Lioliou, J. Wu, S. Papathanasiou, E. Karfopoulos, A. G. Bordagaray, P. Cabral, C. L Lecum, A. Walsh, K. Kanellopoulos, C. Joyce, N. Hartmann, J. O. Willums, "Impact Of Electric and Plug-In Hybrid Vehicles on Grid Infrastructure – Results from the Merge Project", CIGRE Conference, Paris, France, Aug. 2012

[DSOF] E.DSO report "Flexibility: The role of DSOs in tomorrow's electricity market".

[CFDL] CEER conclusion paper on "*Flexibility Use at Distribution Level" , July 2018*

[ECNC] EU consulation paper on "Priority list for the development of Network Codes and guidelines on electricity for the period 2020-2023 and on gas for 2020 (and beyond)"

[CMTD] Helena Gerard, Enrique Israel Rivero Puente, Daan Six: "Coordination between transmission and distribution System Operators in the electricity sector: A conceptual framework", Elsevier Utilities Policy, pp 40-48, 2018

[UCTM] IEC 62559-2:2015 "Use case methodology - Part 2: Definition of the templates for use cases, actor list and requirements list"

[SGCG] CEN-CENELEC-ETSI Smart Grid Coordination Group, «Overview of SG-CG Methodologies» 2014.

[SGRA] CEN CENELEC ETSI Smart Grid Coordination Group, «Smart Grid Reference Architecture» 2012.

[OUML] Object Management Group Unified Modelling Language (OMG UML) Superstructure Version 2.0"

[GEFO] Neupane, B., Siksnys, L., & Pedersen, T. B. (2017). Generation and evaluation of flex-offers from flexible electrical devices. In e-Energy 2017 - Proceedings of the 8th International Conference on Future Energy Systems (pp. 143-156). Association for Computing Machinery. https://doi.org/10.1145/3077839.3077850

6. Annex A: Use case template

Section 1: Description of the use case

- **Scope and objectives of use case**

Scope and objectives of the use case	
Scope	*The scope defines the limits/boundaries of the use case.*

List of business Roles & Objectives	*List of related business roles and objectives.*
	• *Business Roles*
	  ○ *Objective 1*
	  ○ *….*
	  ○

- **Narrative of use case**

Narrative of use case
Short description
Short text intended to summarize the main idea as service for the reader who is searching for a use case or looking for an overview. Recommendation: This short description should have not more than 150 words. Describes the intent of the actor in performing the use case, relevant actions and explain key concepts on the domain.
Complete description
Complete Description Provides a complete narrative of the use case from a user's point of view, describing what occurs when, why, with what expectation, and under what conditions. This narrative should be written in plain text so that non-domain experts can understand it. The complete description of the Use Case can range from a few sentences to a few pages. This section often helps the domain expert to think through the user requirements for the function before getting into the details required by the next sections of the Use Case.

- **Key Performance Indicators**

Important Key performance indicators (KPIs) related to the use case objectives.

Key performance indicators			
ID	**Name**	**Description**	**Reference to mentioned use case objectives**

- **Use case conditions**

Use case conditions
Assumption(s)
General assumptions about systems' configurations, statuses etc.
Precondition(s)
Describes what condition(s) should have been met prior to the initiation of the use case, such as prior state of the actors and activities

- **Further information to the use case for classification/mapping**

Classification information
Relation to other use cases
Link to other use cases of the project. The type of relation like "include", "extends", "invokes" might be used in order to specify this relation in more detail.
Level of Depth
The conceptual level of the use case e.g. high level, detailed, or specialized.
Prioritization
Prioritization of UC in the context of the project. Level definition may differ e.g. mandatory/optional, high/medium/low.
Generic, regional or national relation
Used for describing that the UC refers to regional or national specific circumstances (like laws) or project-specific details.
Nature of the use case
Used to classify the viewpoint of the UC e.g. technical, business/market, test etc.
Further keywords for classification
Keywords for classification of the UC.

- **General Remarks**

General Remarks

Includes any additional information that do not fit in any other category.

Section 2: Use case diagram

Diagram(s) of use case
Refers to UML diagrams (e.g. use case, activity, sequence) or graphics that elaborate the understanding of the UC.

Section 3: Technical Details

- **Actors**

Actors			
Actor name	**Actor type**	**Actor description**	**Further information**
The name of the actor.	*Classification of actor (e.g. person, system, device or application)*	*A short description of the actor.*	*Further information specific to this use case (optional).*

- **References**

References						
No.	**Type**	**Reference**	**Status**	**Impact**	**Originator / Organization**	**URL**
	e.g. standards, regulation, contract, others like publications	***name***	*The status of the referenced document.*	*Main influence to the use case.*	*Author of the document.*	*If publicly available, a link to the reference*

Section 4: Step by step analysis of use case

- **Overview of scenarios**

The table provides an overview of the different scenarios of the use case like normal and alternative scenarios.

Scenario conditions						
No.	**Scenario Name**	**Scenario description**	**Primary Actor**	**Triggering Event**	**Pre-condition**	**Post-condition**

- **Steps – scenarios**

The following table provides a detailed description (step-by-step analysis) of each scenario of the UCs.

Scenario									
Scenario name:			**Collect flexibility information from flexibility predictor**						
Step No.	**Event**	**Name of Process / Activity**	**Description of Process/ Activity**	Service	**Inf. Producer (Actor)**	**Inf. Receiver (Actor)**	**Inf. Exchanged**	**Requirements, R-ID**	

Section 5: Information exchanged

This section will provide the detailed description of the information exchanged in the scenario steps. It is a plain text information with the unique information id and the name of the information exchanged. Sometimes, the information exchanged needs to meet some of the requirements specified in the next section.

Information exchanged			
Information exchanged ID	**Name of information**	**Description of information exchanged**	**Requirements R-ID**

Section 6: Requirements (optional)

Requirements (optional)		
Categories ID	**Category name**	**Category description**
Requirements ID	**Requirement name**	**Requirement description**

Section 7: Common terms and definitions

Provides a common glossary for all use cases

Common terms and definitions	
Term	**Definition**