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Final report: Integrated business platform of distributed energy resources – HEILA

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Research report 101

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Preface

This report is the summary on the results of the ”Integrated business platform of distributed energy resources – HEILA” project realized by LUT University, Tampere University and VTT. The project was started in March 2017 and finalized during the summer 2019. The report introduces the work in different work packages and tasks, and includes the main results, which are described in more detail in various international conference and journal publications, theses works and in other documents. The main funding of the project has been provided by Business Finland. The following companies have also participated in the funding and the work of the steering group: Fingrid Oyj, Helen Oy, Helen Sähköverkko Oy, Lempäälän Energia Oy, PKS Sähkönsiirto Oy (representing R4 consortium), Tampereen Sähköverkko Oy, Convion Oy, GreenEnergy Finland Oy, FinnEnergia Oy, Liikennevirta Oy, MSc Electronics Oy, Nokia Solutions and Networks Oy, Siemens Oy, Wapice Oy.

Lappeenranta and Tampere, September 2019

Authors

Abstract

Energy systems are in a major process of transition from both technology and business perspective. The amount of distributed generation is increasing, load profiles are changing and new types of controllable and uncontrollable resources are being connected to the system (e.g. storage units, electric vehicles). In general, these resources are called distributed energy resources (DERs). The role of microgrids, energy communities and aggregators (virtual power plants) is being particularly emphasized in the electrical system because they create an opportunity for new kind of flexibility provided by DERs, but also introduce new challenges to energy system management. Business potential of intelligent energy solutions is enormous but there are still major barriers that block most of the novel business opportunities in the present energy system. One of the most significant technical barrier is the lack of widely accepted interoperable information exchange solution (data model and interfaces) that is easily accessible and fulfills business needs by all parties dealing with the energy system.

HEILA project aims to define, implement and demonstrate an integrated business platform of DERs for information exchange between energy market participants. The first implementation of such a platform will be realized during the project to integrate smart grid demonstrations in Finland to develop, test, pilot and finally also commercialize new smart energy system functionalities consisting of interactions and impacts of multiple participants. Development of such a system begins as a national smart grid demonstration platform in Finland but will be designed to support Europe wide deployment of the system.

Contents

Nomenclature

Acronyms

AES	Advanced Encryption Standard
AES-256	Advanced Encryption Standard with 256 bits digest
AMI	Advanced Metering Infrastructure
AMS	Aggregator Management System
ASDU	Application Service Data Unit
BESS	Battery Energy Storage System
CA	Common Address
CIM	Common Information Mode
CRP	Conditional Re-Profiling
DER	Distributed Energy Resource
DMS	Distribution Management System
DSO	Distribution System Operator
EAI	Enterprise Application Integration
EC	European Commission
ELK	Elasticsearch, Logstash, and Kibana
ESB	Enterprise Service Bus
ESP	Encapsulating Security Payload
EU	European Union
EV	Electric Vehicle
FCR	Frequency Containment Reserve
FCR-N	Frequency Containment Reserve for Normal Operation
FMP	Flexibility Market Platform
GPS	Global Positioning System
HLUC	High-Level Use Case
HTTP	Hypertext Transfer Protocol
HTTPS	Hypertext Transfer Protocol Secure
ICT	Information and Communication Technology
IEC	International Electrotechnical Commission
IED	Intelligent Electronic Device
IOA	Information Object Address
IP	Internet Protocol
IT	Information Technology
JSON	JavaScript Object Notation
JSON-LD	JavaScript Object Notation for Linked Data

LSVPP	Large Scale Virtual Power Plants
LUT	LUT University
LV	Low-Voltage
LVDC	Low-voltage Direct Current
MGMS	Microgrid Management System
MMS	Manufacturing Message Specification
MO	Microgrid Operator
MQTT	Message Queuing Telemetry Transport
MV	Medium-Voltage
OPF	Optimal Power Flow
OSI	Open Systems Interconnection
PC	Personal Computer
PK	Public Key
PPP	Public–Private Partnership
PUC	Primary Use Case
PV	Photo-Voltaic
RDF	Resource Description Framework
RMP	Reserve Marketplace
RSA	Rivest–Shamir–Adleman algorithm
RTDS	Real-Time Digital Simulator
SAU	Substation Automation Unit
SCADA	Supervisory Control And Data Acquisition
SGAM	Smart Grid Architecture Model
SHA-512	Secure Hash Algorithm with 512 bits digest
SQL	Structured Query Language
TAU	Tampere University
TCP	Transmission Control Protocol
TLS	Transport Layer Security
TSO	Transmission System Operator
UDP	User Datagram Protocol
UML	Unified Modeling Language
URI	Uniform Resource Identifier
VPN	Virtual Private Network
VTT	Teknologian tutkimuskeskus VTT Oy
XML	Extensible Markup Language

1 Introduction

Energy systems are in a major process of transition from both technology and business perspective. The amount of distributed generation is increasing, load profiles are changing and new types of controllable and uncontrollable resources are being connected to the system (e.g. storage units, electric vehicles). In general, these resources are called distributed energy resources (DERs). The role of microgrids, energy communities and aggregators (virtual power plants) is being particularly emphasized in the electrical system because they create an opportunity for new kind of flexibility provided by DERs, but also introduce new challenges to energy system management. Business potential of intelligent energy solutions is enormous but there are still major barriers that block most of the novel business opportunities in the present energy system. One of the most significant technical barrier is the lack of widely accepted interoperable information exchange solution (data model and interfaces) that is easily accessible and fulfills business needs by all parties dealing with the energy system.

HEILA project aims to define, implement and demonstrate an integrated business platform of DERs for information exchange between energy market participants. The first implementation of such a platform will be realized during the project to integrate smart grid demonstrations in Finland to develop, test, pilot and finally also commercialize new smart energy system functionalities consisting of interactions and impacts of multiple participants. Development of such a system begins as a national smart grid demonstration platform in Finland but will be designed to support Europe wide deployment of the system.

The development of platforms that allow evaluating the direct effects and interactions of different resources in a real-world environment can help to explore the alternative future scenarios and paths of future energy business. The project will build such a testing platform by combining laboratories, simulation resources and pilots of the project research partners. Even though some of the related pilots are already being explored extensively, they are lacking co-operation because most of them are focusing on individual local applications and lack comprehensive view of multiple participants of energy system.

The project defines multiple functionalities and requirements that allow integrating DERs into different business models of electrical energy system and determines the information and communication technology (ICT) and automation architecture to realize these functionalities. The obtained architecture will be the basis for the implementation of an information technology (IT) solution for the target development and demonstration of integrated platform. The project also develops and implements the interface between geographically dispersed microgrids to the metadata register which provides static information and flexibility properties of DERs to be used by flexible resources (DERs and microgrids), smart energy system functionalities and market players (Aggregators, DSOs, transmission system operator (TSO), etc.).

This final report summarizes the whole HEILA project. The mid-term report finalized in May 2018 has served as a starting point for this report. In addition to these reports, results of HEILA project have been published in several international publications and one MSc thesis, as listed below. Further publications are expected also after the end of the project.

- Aleksei Mashlakov, Ville Tikka, Samuli Honkapuro, Pyry Lehtimäki, Sami Repo, Antti Keski-Koukkari, Matti Aro, Rinat Abdurafikov, and Anna Kulmala. Sgam use case definition of an information exchange architecture. In *CIRED Workshop 2018: Microgrids and Local Energy Communities*, page 0503. International Conference and Exhibition on Electricity Distribution CIRED, 2018
- Aleksei Mashlakov, Ville Tikka, Samuli Honkapuro, Jarmo Partanen, Sami Repo, Anna Kulmala, Rinat Abdurafikov, Antti Keski-Koukkari, Matti Aro, and Pertti Järventausta. Use case description of real-time control of microgrid flexibility. In *2018 15th International Conference on the European Energy Market (EEM)*, pages 1–5. IEEE, 2018
- Anna Kulmala, Andrea Angioni, Sami Repo, Davide Della Giustina, Antimo Barbato, and Ferdinanda Ponci. Experiences of laboratory and field demonstrations of distribution network congestion management. In *IECON 2018-44th Annual Conference of the IEEE Industrial Electronics Society*, pages 3543–3549. IEEE, 2018
- Ville Tikka, Aleksei Mashlakov, Anna Kulmala, Sami Repo, Matti Aro, Antti Keski-Koukkari, Samuli Honkapuro, Pertti Järventausta, and Jarmo Partanen. Integrated business platform of distributed energy resources–case finland. *Energy Procedia*, 158:6637–6644, 2019
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- Antti Keski-Koukkari, Aleksei Mashlakov, Ville Tikka, Anna Kulmala, Sami Repo, Samuli Honkapuro, Matti Aro, and Pertti Järventausta. Architecture of integrated business platform of distributed energy resources and integration of multipower laboratory. In *The 25th International Conference adn Exhibition on Eelectricity Distribution (CIRED)*. International Conference and Exhibition on Electricity Distribution CIRED, AIM, 2019
- Anna Kulmala, Ville Tikka, Sami Repo, Antti Keski-Koukkari, Aleksei Romanenko, Peyman Jafary, Aleksei Mashlakov, Samuli Honkapuro, Pertti Järventausta, Jarmo Partanen, and Kari Mäki. Information Exchange Plat-form for Enabling Ancillary Services from Distributed Energy Resource. In *2019 16th International Conference on the European*

Energy Market (EEM), pages 1–5. IEEE, 2019

- Antti Keski-Koukkari. Architecture of smart grid testing platform and integration of multipower laboratory. M.Sc. Thesis, Tampere University of Technology, 2018

2 Use case descriptions

2.1 Use case methodology

The primary goal of the first work package of HEILA was to define a scalable smart grid architecture able to support integration of DERs into different business models of electrical power system. This goal was realized in accordance with the SGAM use case methodology initiated by the Smart Grid Mandate M/490 to enhance standardization and development in the smart grid field [9]. In this methodology, the use case represents a particular functionality of the smart grid and describes this functionality based on an application of use case methodology and its use case templates, and the SGAM framework. In HEILA project, this methodology was customized for a continuous iterative and incremental process described in Figure 1. The developed methodology enabled a systematic approach to design HEILA smart grid architecture with all-encompassing business and technical viewpoints including functional descriptions and their requirements for information, communication and component levels.

In what follows, details of HEILA SGAM-based use case methodology are explained. HEILA methodology started with *Use Case Aggregation* in order to provide a state-of-the-art review of the innovative and envisioned use cases related to the concept of DER integration. At that stage, the generic use cases were gathered into clusters from large European Union (EU) projects as well as from HEILA work packages and workshops held on the topic. The methodology continued with *Use Case Extraction* that aimed to define the most promising use cases from the previously derived, to identify the objectives and roles of business actors for these use cases, and to determine success scenarios i.e. functionalities and modes of operation needed to realize these use cases. The outputs of this step incorporated a concept view on the architecture and general use cases describing the functional implementation of the business goals. The descriptions were constructed iteratively and formulated with a short use case template. *Use Case Detalization* further developed general use cases into detailed use cases described with the International Electrotechnical Commission (IEC) 62559-2 template [10]. At this stage, components, functionalities, exchanged information, and technical requirements were included into this detailed template. The visualization of the detailed use cases was done by the unified modeling language (UML) use case and sequence diagrams. The detailed use cases were written in series (more use cases added all the time) and more details added to each use case while iteration process towards a final architecture. This step also specified the minimum technical requirements of use cases that predefined the possible types of implementations.

The detailed use cases chosen for the implementation went through the process of *SGAM Mapping* on the SGAM plane with the main focus on identifying the related standards and protocols for the architecture. The outcomes of this consistent mapping included a particular architectural solution

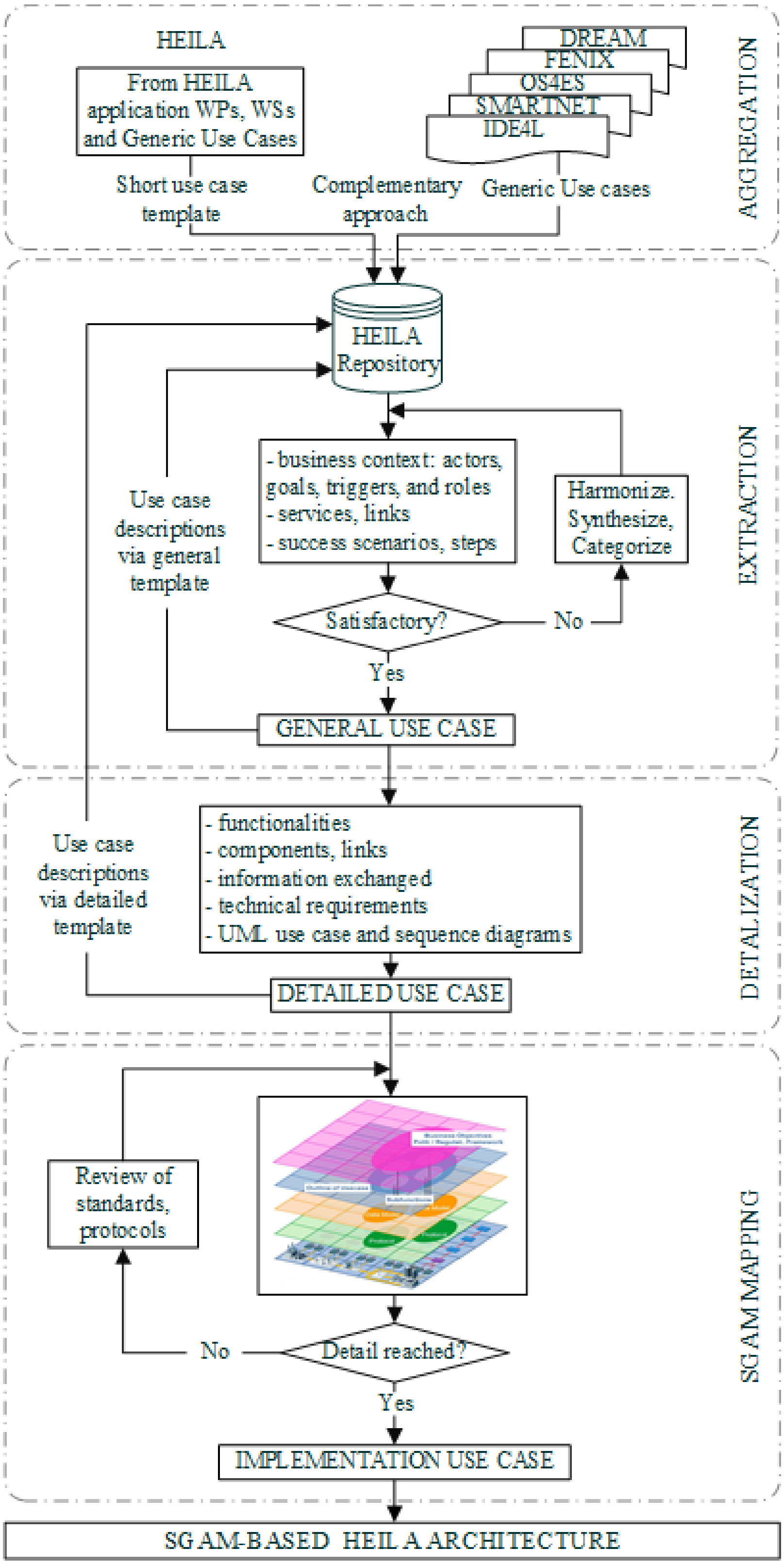

Figure 1: HEILA SGAM-based use case methodology.

that delivered the preliminarily described functionality of detailed use cases and objectives of general use cases. The mapping process started from Business and Functional layers that were mostly defined by general use cases during the *Use Case Extraction* stage. The mapping process continued with the architectural description that covered information, communication and component levels. At this stage, all the implementation details were considered and relied on the detailed use cases described during *Use Case Detalization*. The architectural mapping started with the Component layer where type and location of required hardware components were identified. The data model standards (canonical model) and information exchange protocols were defined in the Information layer. In the end, the communication protocols were specified for the Communication layer. Finally, the architecture (in terms of infrastructure, information, communication, and functions) was derived and used for the implementation.

Figure 2 visualizes the links between general use case, detailed use cases, and implementation use cases on each SGAM layer. General use cases describe the concept (left-side column), detailed use cases (in the middle) provide the architecture view, and the implementations are based on right-side columns further adding implementation requirements to the detailed use cases. The visual representation of the use cases is formalized in SGAM Toolbox [11] that is an extension of "Enterprise Architect" software. The examples of the SGAM visualization for the implementation use cases can be found in [12] and [6].

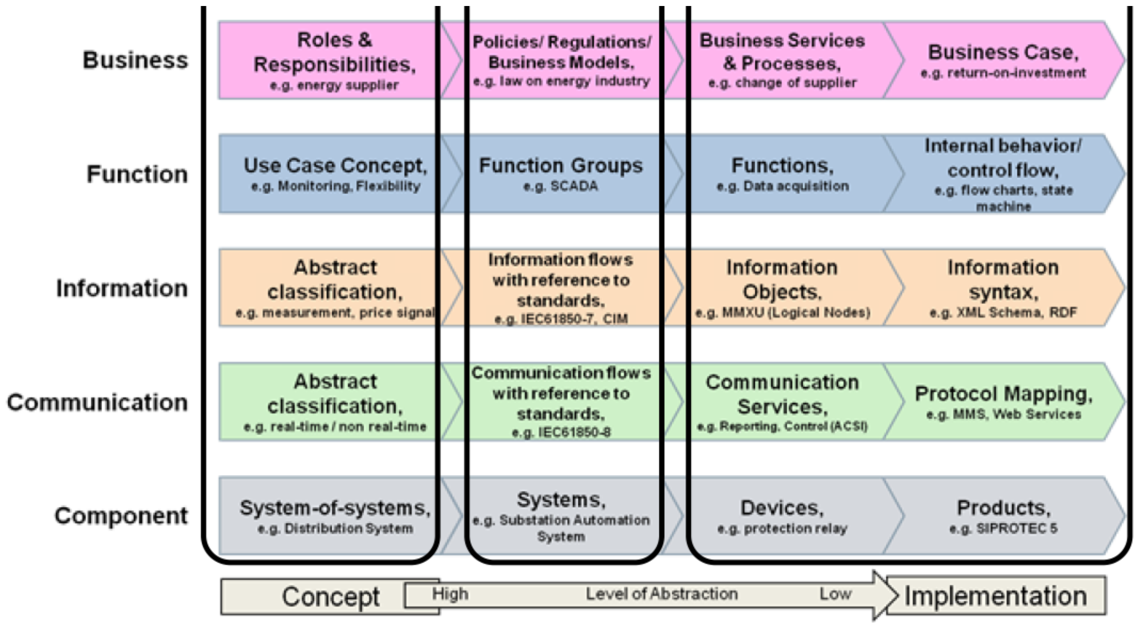

Figure 2: Relation of use case templates and the use case analysis pattern based on the SGAM framework.

2.2 Review of use cases in other projects

The increasing trend of replacing traditional centralized forms of electricity production with renewable DERs has created the need to develop power systems throughout Europe. Therefore, smart grids and its applications have been already studied for several years with the aim of harmonizing European energy system development in the same direction. In this section, some focal use cases of other European smart grid projects are gathered. They were reviewed as a starting point when defining the architecture in HEILA project during the *Use Case Aggregation* phase. For the HEILA project, a dozen of the previously implemented smart grid projects have been reviewed and the most focal six of them are shortly presented next including the crucial use cases from the projects collected in Table 1.

IDE4L was a 3-year demonstration project funded by European Commission (EC), with a vision to develop distributed and hierarchical automation solution and functionalities for complete distribution grid management, which enables clean and reliable energy for the future [13]. **OS4ES** "Open System for Energy Services" was also a 3-year EC project, with a central aim to provide a solution that would close the information, communication and cooperation gap between DERs and DSOs [14]. **DREAM** "Distributed Renewable resources Exploitation in electric grids through Advanced hierarchical Management" was a EC funded project that included partners which focused on three main features: 1) Market benefits from empowered consumers and prosumers. 2) From "passive" to "active" smart distribution grids. 3) Efficient generation from distributed renewable sources [15]. **SmartNet** project aims to provide optimized instruments and modalities to improve the coordination between the grid operators at national and local level and the exchange of information for monitoring and for the acquisition of ancillary services from subjects located in the distribution segment. It receives funding from the European Union's Horizon 2020 research and innovation program [16]. **FENIX** "Flexible Electricity Network to Integrate the eXpected 'energy evolution'" had an objective to boost DERs by maximizing their contribution to the electric power system, through aggregation into large scale virtual power plants (LSVPP) and decentralized management [17]. Developing an integrated research infrastructure for smart grid systems is the target of the EU-funded **ERIGrid** "European Research Infrastructure supporting Smart Grid Systems Technology Development, Validation and Roll Out - project", where 18 of Europe's top research institutions join forces in order to pool together their know-how and improve research infrastructures within the smart grid sector [18]. The lack of system validation approaches for Smart Grids is especially addressed by ERIGrid.

Table 1 summarizes the use cases from the six selected projects that dealt the same topics we addressed in the HEILA project. The use cases were divided into three clusters and more specifically into general or high-level use cases (HLUCs) and later into detailed or primary use cases (PUCs). In this table, the used clusters are: Business, Control and Monitor. Business cluster included market and operational interactions among Aggregator, DSO and TSO. Control cluster incorporated Real-time control- and Power quality-related HLUCs. Monitor cluster was devoted only to Real-time monitoring since that was the main issue we were dealing with in our monitoring use cases in HEILA.

2.3 General use cases

Following the analysis of the focal use cases of the European smart grid projects described above and generating own use cases, a few general use cases were extracted as being essential in HEILA project. The general use cases were focused on processing and exchange of information between the following main actors: DERs, microgrid operators (MOs), aggregators, DSOs, TSOs, marketplaces, and third-party service providers. The selected general use cases were "microgrid monitoring", "microgrid participation in the market as FCR-N", and "provision of microgrid flexibility services to DSO". List of the main actors utilized in HEILA general use cases is presented in Table 2. Each of the use cases was described from the point of MO, DSO, and Aggregator as the main actors. In what follows, a summary of these use cases is provided, while the full version of the general use cases can be found in Appendix I of the the present report.

2.3.1 Microgrid monitoring

The monitoring use case is the simplest but a crucial one. The main actor is the MO, who monitors the DERs of the microgrid. The MO acquires, processes, and stores raw measurements, and extracts and publishes the required information. The main objectives are continuous verification of the states of the flexibility reserves / services of the microgrid as well as retrieval of information required by aggregators in order to offer microgrid reserves / services in the flexibility and reserve markets. Where needed, the MO uses third-party services, such as weather forecasting, to estimate the expected flexibility in a short-time. The monitoring use case also includes provision of technical data to the DSO related to the potential for island or off-grid operation.

2.3.2 FCR-N

This use case shows how flexible DERs of microgrid could participate in a lucrative hourly market for FCR-N through aggregator. The latter is the main actor in the use case, who collects and processes the information about available volumes of active power reserves published by the MOs, and prepares and submits price bids to the FCR-N market. Having obtained the results of the trading session, the aggregator optimizes the distribution of the to-be-maintained reserves between MOs. Consequently, the MOs perform internal rescheduling of the power flows of DERs within microgrids, and monitor and control the delivery of active power regulation service. Finally, the MOs deliver verification reports for financial settlement to aggregator that verifies the amounts of maintained and activated reserves by each of the MOs and delivers aggregated

Table 1: Generic use cases from EU projects considered most relevant for HEILA project.

Cluster	HLUC	PUC	Project
Business	Market interaction among Aggregator, DSO/TSO	Flexibility negotiations between the Flexibility Provider, Aggregator, and served roles (such as DSO, balance responsible party (BRP), and TSO)	OS4ES
		Aggregation of DERs in commercial virtual power plants (VPPs)	FENIX
		Market bidding and service procurement	IDE4L
		Operation of a local market by the DSO	SmartNet
	Operation interaction among Aggregator, DSO/TSO	Volt/Var Control – Dynamic, Static, Optimization	OS4ES
		LV (MV) cell provision of flexibility	DREAM
		LV (MV) network congestion management based on procurement of scheduled re-profiling (SRP) and conditional re-profiling (CRP) services provided by Aggregators for a local market	IDE4L
		Sharing balancing responsibility between DSO and TSO	SmartNet
		Decentralized peer-to-peer control (contains pre-emptive steps to determine flexibility with model calculations)	DREAM
		Aggregation of DERs in VPP. (Aggregation, scheduling)	OS4ES
Control	Real-time control	Real-time flexibility release for the LV cell in emergency situations (e.g. congestion)	DREAM
		Local LV control to solve a contingency in emergency situation	DREAM
		LV (MV) network congestion management based on DSO's resources and DERs	IDE4L
		Frequency control – Primary, Secondary, and Tertiary	OS4ES
	Power quality	Use of flexibility in active power networks	ERIGrid
Monitor	Real-time monitoring	LV (MV) network real-time monitoring and state estimation	IDE4L
		Certified Energy Market	OS4ES

Table 2: Main actors of general use cases deployed in HEILA project.

Actor's Name	Actor's Type	Actor's Description
Distributed Energy Resource (DER)	Physical resource	A distributed physical resource for power generation, demand response, and storage.
Prosumer	People	A provider of DERs (owned himself or together with other partners), and contract customer for microgrid operator that is allowed to monitor and control its DERs.
Microgrid Operator (MO)	Organization	A housing company, cooperative or service company that optimizes the operation of the physical microcomputer network, manages the control of the energy resources of the micro-network, aims to increase microgrid efficiency by selling available DER flexibility[1], and is responsible for the security of the dedicated network (= physical micro-network).
Aggregator	Organization	An electricity market participant or service provider that pools available active power reserves of microgrids and resells them in different electricity markets.
Distribution System Operator (DSO)	Organization	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the distribution system that aims to improve power quality (e.g. congestion management, ramping issues, voltage quality, etc.) in distribution network and reduce expenses by using microgrid flexibility.
Transmission System Operator (TSO)	Organization	A natural or legal person responsible for operating, ensuring the maintenance of and, if necessary, developing the transmission system that aims to optimize the performance of the transmission grid with low-cost reserves of microgrids.
Reserve Market	Organization	An organization that provides a market place to facilitate trading with frequency containment reserves for a fee.
Service provider	Organization	A vendor that provides IT or AI solutions and/or services to microgrid operator or aggregator for a fee.
Flexibility Market	Organization	An organization that provides a market place to facilitate trading of flexibility services for a fee.

[1] Available DER flexibility means how much of a certain ancillary service type remains after taking into account "locked" amounts that have been already sold or required to cover base needs.

verification data to TSO.

2.3.3 Flexibility services for DSOs (DSO Flexibility)

In this use case, the primary actor is the DSO, whose main target is to make use of the flexibility services provided by DERs to improve operation of a certain part of the distribution network. The MOs estimate the amounts of flexibility services they are able to offer to the DSO as part of microgrid monitoring process and publish this data for aggregator(s). The aggregators publish area- or microgrid-specific offers to the market place. The market place transmits this information to the DSO and the latter runs an internal process to define the total amounts of services to buy. The DSO then notifies market place of accepted volumes by area or microgrid, and the market place settles the contract between the aggregators and DSO. The aggregators proceed with distribution of accepted volumes to the MOs, who, in their turn, perform internal rescheduling of DERs and control them to provide the services. Similar to the FCR use case, the MOs prepare verification reports for financial settlement.

When the platform supports FCR and DSO Flexibility it would be ready to support additional use cases. For example, procurement of frequency regulation services by DSO for temporary island operation.

2.4 Detailed use cases

The detailed use cases further specified the general use cases by representing the business actors by corresponding automation actors and defining these automation actors in terms of interfaces, databases and functions. For instance, if the general use cases consisted only of business entities like the DSO, the Prosumer, the Aggregator, etc., the detailed use cases contained the systems used by those business entities and their interactions, e.g. the distribution management system (DMS), intelligent electronic device (IED), etc. The overall view on the use case semantic between the actors of detailed and general use cases is displayed in Figure 3. The description of the detailed actors can be found in Table 3 and the use case descriptions are available in Appendix II of the present report.

2.5 Implementation use cases

The final step was a development of the implementation use cases that would demonstrate the business operations associated with the use of DERs. According to the results obtained at the detalization phase, it was decided that FCR and DSO Flexibility use cases will be demonstrated in HEILA platform while the monitoring use case was included in these two as the core of their operation. The implementation use cases are well combination of architecture requirements where the microgrid resources could be adopted for an existing energy market structure (FCR) and for future smart grid scenarios (DSO Flexibility). Moreover, these use cases operate in different time frames that introduce diverse requirements for the data exchange and can be used

Table 3: Main actors of detailed use cases deployed in HEILA project.

Actor's Name	Actor's Type	Actor's Description
Intelligent Electronic Device (IED)	Device	A microprocessor-based controller.
DER IED	Device	A generic device that is responsible for control and monitoring of DER.
Automation System (AS)	IT system	A generic automation system of building or home that involves the control and automation of lighting, heating (such as smart thermostats), ventilation, air conditioning (HVAC), and security, as well as home appliances such as washer/dryers, ovens or refrigerators/freezers.
Customer Energy Management System (CEMS)	IT system	A generic information system (e.g. HEMS, BEMS, etc.) for monitoring and control of customer side flexible resources (DERs and AS) that manages their consumption and generation portfolios.
Microgrid Management System (MGMS)	IT system	A system that aggregates and processes technical information about microgrid for different time periods to optimize scheduling of its resources in order to guarantee quality of supply as well as to allow maximum participation of microgrid resources in flexibility services.
Aggregator Management System (AMS)	IT system	A system that acquires and processes flexibility information of microgrids and other controllable resources on different time-scales to propose flexibility services on market platforms and provide the management of such services.
Distribution Management System (DMS)	IT system	A DMS advanced by applications designed to use resource flexibility to support of the quality of supply of distribution network.
Flexibility Market Platform (FMP)	IT system	A platform for trading of flexibility services between aggregators and grid operators.
Transmission System Operator Energy Management System (EMS)	IT system	A TSO EMS advanced by applications designed to monitor, control, and optimize the performance of the transmission grid with low-cost reserves of microgrids.
Reserve Market Platform (RMP)	IT system	A platform for trading of frequency containment reserves on hourly market.
Service Provider Platform (SPP)	IT system	A system that provides the services of weather and market price forecasts for management systems of aggregator and microgrid operator.

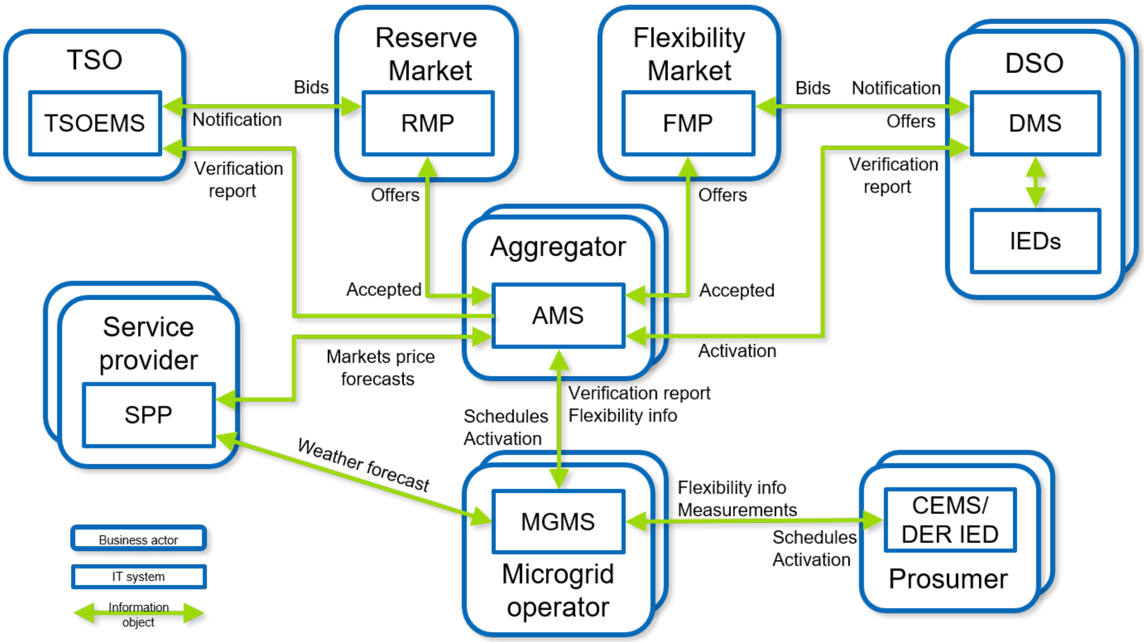

Figure 3: Overview of general and detailed use cases.

to check the performance of the platform during their simultaneous operation at later stages. The details of the implementation use cases are presented in Appendix III of the present report.

2.6 SGAM use case architecture

The preliminary architecture of smart grid use cases studied in HEILA project is briefly introduced here. Also an introduction to different kind of architectures is given. Architectures may be defined for many kind of systems. In HEILA project, the focus of architecture is in the system of systems viewpoint. This means a description of multiple systems and stakeholders how they interact and cooperate. Each system and stakeholder has internal architectures which are not discussed in detail here. One specific system of systems may appear for different actors very differently and may appear centralized and distributed at the same time depending on the observer. Even if the introduction of architectures presents clearly the differences of centralized, decentralized and distributed architectures, the practical architectures are usually hybrid systems where aspects from all architecture types exist in parallel. Many times system of systems are hierarchical systems where it is important to understand how the coordination of complete system is realized which might be done in design or operational phase.

Figure 4 visualizes different architecture types. A node represents a decision making point in the architecture. A link is a connection (information exchange) between two decision making points. Centralized architecture brings all information to one point where the decisions are made. Typical example of centralized architecture is a Nordpool market place (centralized system in Figure 5). Decentralized architecture decomposes the global monitoring and control task to partial or/and local tasks which are only loosely connected to each other (green links in Figure 4) or might miss the connection completely. An example of decentralized system is a combination of several markets operated in sequence (Figure 5). Distributed architecture is the most difficult to understand, because truly distributed architectures are very few. All decision making nodes in distributed architecture should be equal, no one should make decisions instead of them. The idea of decision making is based on autonomous decision making and communication / negotiation with neighboring nodes. In that way single decision making node may understand more about global tasks in addition to local tasks dedicated to it. Bilateral trading in Figure 5 is an example of distributed architecture where different market participants create a meshed structure without a central controlling unit.

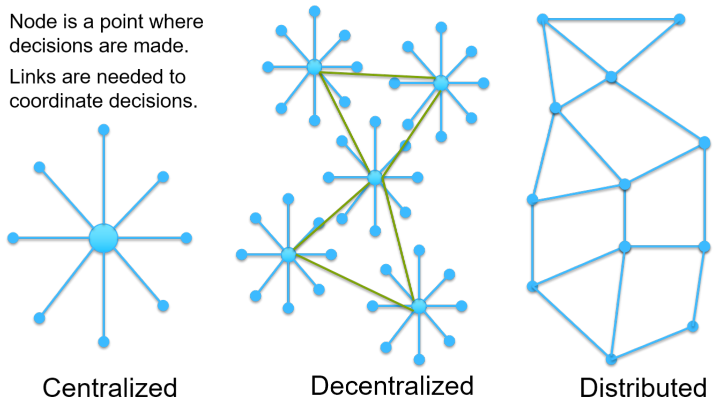

Figure 4: Architecture types.

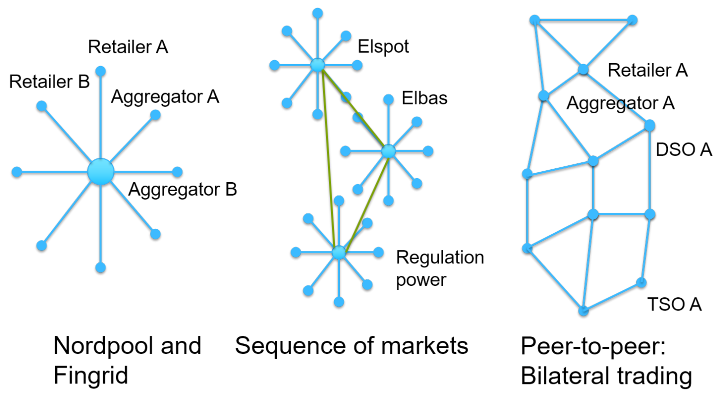

Figure 5: Examples of architecture types from market perspective.

Figure 6 represents two examples of distribution grid management. The centralized architecture is based on supervisory control and data acquisition (SCADA) system used for remote real-time monitoring and control of primary substations, advanced metering infrastructure (AMI) used for low voltage network management, and SCADA for microgrids where DSO receives real-time information. All these are integrated together in one centralized system which is typically implemented as an enterprise application integration (EAI) or enterprise service bus (ESB) solution. This is an IT integration viewpoint for the architecture.

The same system looks like decentralized architecture, if it is considered from the technical viewpoint of DSO. Grid management system includes hierarchy (control centre, substations and microgrids) and some decisions are made in decentralized way without central decision. Substation automation system merging and utilizing information from IEDs is a typical example of decentralized system working in tight connection with a centralized system. IEDs at substation or along medium voltage feeder may also operate at the same time in distributed architecture. An example of distributed architecture in grid management is peer-to-peer GOOSE communication of IEDs.

Another example of decentralized architecture is the frequency control system applied in Nordic countries. Primary frequency control is realized by the turbine controllers of synchronous machines which are local controllers (IEDs) utilizing local frequency measurement for the control decision. Secondary frequency control is implemented on national level providing manual adjustments for primary controllers if needed. Frequency control does not have one centralized node where all decisions are made but multiple nodes which operate in parallel and partly in sequence.

Many times the architectures which are said to be distributed are actually more close to decentralized than distributed architecture. Typically distributed architecture includes a coordinator or a master which has more power to make decisions compared to other decision making nodes. In that case the architecture is a hybrid architecture of distributed and centralized/decentralized architectures. An example of such system is a microgrid management based on blockchain technology where exists multiple equal decision makers (e.g. IEDs of DERs) communicating peer-to-peer and a microgrid central controller communicating with Aggregator, DSO, etc. and making decisions external to microgrid.

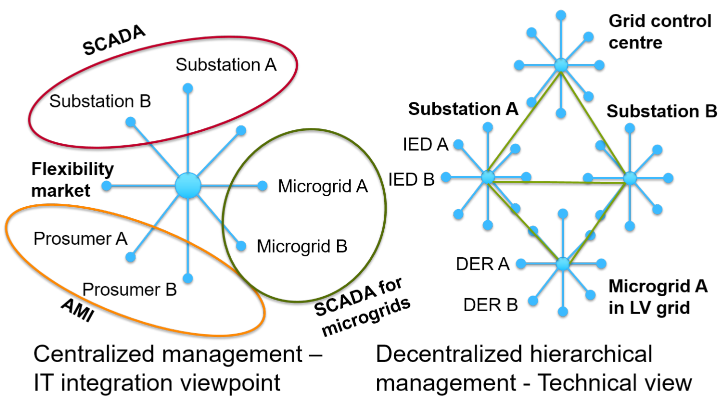

Figure 6: Examples of architecture types from market perspective.

The information exchange architecture proposed in HEILA is decentralized and aims to enable efficient real-time data exchange between all energy market actors (including DER owners). The future energy system will include both distributed customer driven renewable based parts and centralized market actor driven systems and is, therefore, inherently a decentralized system. The concept of the proposed decentralized information exchange architecture in business use is represented in Figure 7. The basic operational principle of the information exchange platform is that all real-time communication happens directly between the actors required to communicate with each other and not through any centralized point. The need to build numerous dedicated point-to-point communication links is being tackled by utilizing a unified interface at the connection point of each actor. All communication utilizes the public internet and no dedicated communication channels are built.

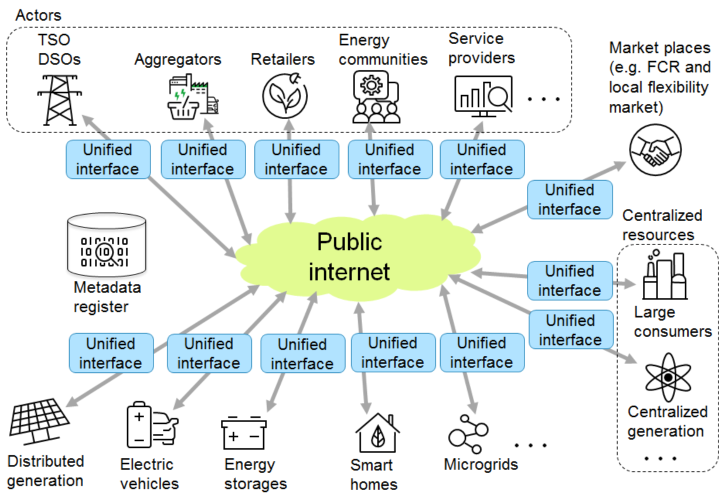

Figure 7: The concept of the decentralized information exchange architecture.

3 HEILA platform

3.1 General introduction

HEILA platform is a method to exchange information between laboratories, pilots and real facilities of all market participants (Figure 8). The platform itself does not realize the use cases, but enables the information exchange of market participants, DERs, etc. to test and demonstrate complete use cases. The information exchange architecture is decentralized but regarding the use cases to be implemented, the platform is technology neutral at all SGAM layers and can support multiple kind of smart grid architectures (e.g. centralized, completely distributed or hybrid decision making) defined by use cases.

Each participant of the platform needs a gateway (Smart API interface [19] defined for a specific use case) to integrate laboratory or pilot site to platform.The gateway maps participant's site specific protocol to the HEILA platform data model defined by Smart API ontology. Within common side of the HEILA platform, everyone will "speak the same language". Therefore every participant will understand not only the syntax but also the semantic contents (canonical data) of the exchanged information. Semantic data contains a payload and at the same time the meaning of the payload. The payload is the actual content of the message, other parts of the message are headers and metadata which are needed to enable payload delivery. The gateway is also easy way to control which data of demonstration site will be published to other participants. It also simplifies the integration of demonstration site to the platform because no changes are required on site itself, only a server communicating with site resources is needed. Site resources may be almost anything like hardware resources (automation system of DER, microgrid, etc.) or software resources (IT system, simulator, etc.).

Figure 9 explains the technical content of HEILA platform in more detail. The gateway is implemented as Smart API client / server. Smart API is based on open source library including programming library and HEILA platform data model defined by Smart API ontology. Several programming languages are supported (Java, C++, C#, Python). Smart API is aimed to exchange information between energy system participants within dynamic environment. It has a data model for energy domain which is extendable. The Smart API also hides the complicated semantic data structure which make it easy to use. Security features of Smart API are basic hypertext transfer protocol secure (HTTPS), messaging can be encrypted and signed, and authenticated utilising OAuth2.

In order to send messages between Smart API-capable actors, a register is preferably needed to organize and manage registration to the HEILA platform and discovery of resources / services included in the HEILA platform. The register includes metadata (information about data itself) of resources / services available in the HEILA platform. Metadata describes a resource (e.g. title,

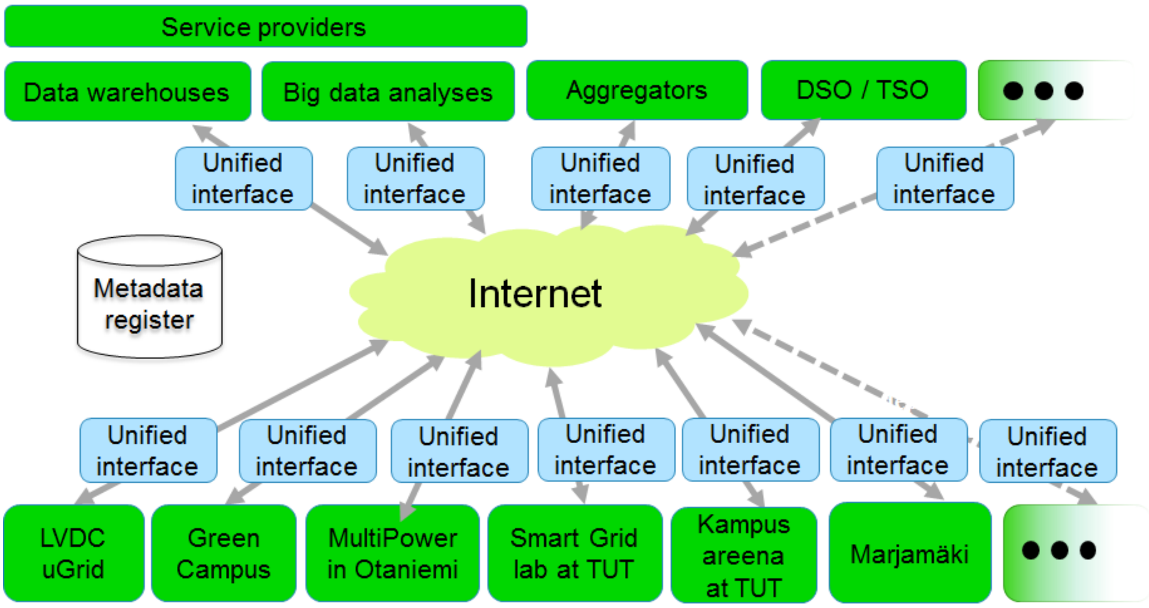

Figure 8: Example of HEILA platform utilization.

abstract, author, and keywords), provides structural information (types, versions, relationships and other characteristics of digital materials), and provides administrative information (e.g. when and how it was created, file type and other technical information, and who can access it). Blue arrows in Figure 9 represent the visualization, registration and discovery parts of the platform.

When two Smart API-capable actors discover each other and they have a contract to exchange information, the messaging between them is realized directly (green arrow). The information exchange can be cyclic, event based or based on subscription. HEILA platform does not have a centralized system where all information should flow. Internally each demonstration, pilot or laboratory (orange and blue parts of Figure 9) organize information flow independently from the HEILA platform (dashed green arrows). The HEILA platform however includes a centralized data warehouse where data flows of demonstrations may be replicated (data warehouse has access and receives data from most of Smart API-capable actors).

The HEILA platform allows variety of resources to be connected with aggregators, DSOs, retailers, or some novel actors (outside of the energy sector). In this way it may emulate existing hierarchical management systems like energy balance management and settlement or distribution grid management. Novel elements like microgrids providing flexibility services for local flexibility service market may be added to platform to realize such functionality and interactions with other participants. Resources may also be connected in completely new way, e.g. realizing a peer-to-peer communication between resources. The platform and especially the metadata register enables demonstrations in very dynamic environment where for example Smart API-capable actors automatically identify if the contract of a resource is changed from

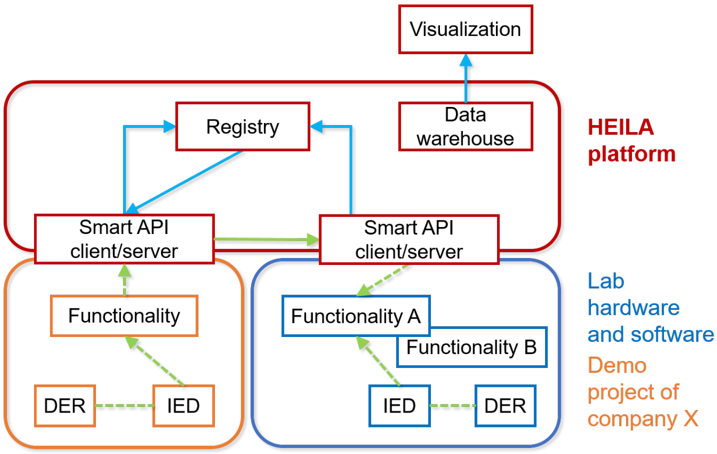

Figure 9: Main parts of HEILA platform and integration of demonstrations, pilots and laboratories to platform.

FCR to local flexibility service.

Because one of the main aims of the HEILA platform is to utilise it as the first version of Finnish smart grid demonstration platform, the platform has to be secure, scalable and easy to utilise. Basic cybersecurity has been built in the Smart API (such as authentication, encryption) and the mandatory use of register metadata for access control allows controlling who has access to specific data. Availability of the complete platform is more complex to guarantee, but the platform may include multiple mechanisms to increase the availability, like utilisation of multiple redundant registers, retransmission of subscribed messages or frequent polling of servers. The most important aspect of platform availability is the fact that there is no single centralized node which might become a bottleneck for the performance of platform.

The scalability of the HEILA platform is very difficult to determine in general, but it is expected to be well scalable because of distributed system architecture. In practice the implementation of use cases and Smart API-capable actors sets a limit for example how frequently and by how many clients it may be polled. These aspects are however strongly influenced during the design phase of a use case and therefore the platform should include and collect good practices for the implementations. HEILA Smart API implementation includes both event based and publish-subscribe type of messaging which might be utilized to relieve the work load of congested servers. Dedicated interfaces including only well specified data are more efficient to utilize compared to interfaces including all possible data. HEILA may operate as well as gateway between the platform and demonstration site. Gateway may hide unnecessary details of demonstration sites from other participants which makes information exchange more efficient.

Another task of gateways is to map demonstration site specific information exchange protocol to the data model of the HEILA platform. The canonical data model of the HEILA platform is an essential requirement for efficient information exchange. Point-to-point type of messaging with multiple different data models would become a nightmare to maintain after some time. Therefore the HEILA platform utilize message-based integration with Smart API as a middleware. Secondly, if demonstration sites utilize standard information exchange protocols, the mapping of protocol becomes reusable, the integration of demonstration sites becomes faster, and the maintenance work of interfaces less demanding task.

3.2 HEILA API

HEILA API was designed to provide scalability and decentralisation. In order to achieve these two characteristics it is important to provide abstraction layers above existing communication protocols and technologies. Such abstraction layers enable quick adoption of additional protocols into the system. I.e. hypertext transfer protocol (HTTP) protocol has been successfully converted to HTTPS by addition of transport layer security (TLS) with only minor modifications to the core of HTTP standard which allows HTTPS to be added on top of HTTP traffic seamlessly for both client and server HTTP endpoints. On a higher abstraction level HEILA generalizes communication even further down to a Request-Response model of communication for transport layer and an abstract level of Smart Grid-specific communication.

3.2.1 Client/Server architecture

From perspective of the open systems interconnection (OSI) model HEILA protocol implements Session and Presentation layers. The session level is implemented above an abstract Transport class. The minimal requirement for transport media is to be able to deliver a single request from client to server and maintain knowledge about the fact of communication until the server does not provide response, which should be as well delivered to the client. This, effectively establishes single-message long communication sessions, that are implemented in transport classes on a case by case basis. However, the requirements allow any transmission control protocol (TCP) based protocol as well as TCP itself to be used as transport protocols. In the case of current implementation two transport classes are implemented, that use HTTP and message queuing telemetry transport (MQTT) protocols.

Tables 4 and 5 present summary of events, logged during the transmission of a single message with MQTT and HTTPS protocols. The comparison of event streams indicates that application logic is isolated from transport in a repeatable way, so that transports can be interchanged seamlessly for Application layer.

3.2.2 Payload factory

The presentation layer is provided by Smart API library above which an abstraction layer has been implemented, that allows substitution of serialization and representation techniques in future. The abstraction layer is provided by the payloadfactory class of HEILA. The class implements

Table 4: Events generated during communication of RMPSearch request over HTTPS transport. Transport-specific events are highlighted.

Event-Emitting Class	OSI Layer	Time	Event Name	Actor
TSO -> Client	Application	May 31st 2019, 03:13:48.225	client_run_request_begin	TSO
Payloadfactory	Presentation	May 31st 2019, 03:13:48.248	client_run_args	TSO
TransportHTTPS-Server	Session / Transport	May 31st 2019, 03:13:48.345	flask_got_post	Registry
Server		May 31st 2019, 03:14:19.982	try_serving_request	Registry
Payloadfactory	Presentation	May 31st 2019, 03:14:20.012	got_request	Registry
Registry	Application	May 31st 2019, 03:14:20.013	registry_update_RMPSearch	Registry
		May 31st 2019, 03:14:20.014	RMP linked to TSO	Registry
Registry -> FakeRedis		May 31st 2019, 03:14:20.018	fake redis write	Registry
Registry		May 31st 2019, 03:14:20.019	RMP_Search_processed	Registry
Payloadfactory -> FakeRedis	Presentation	May 31st 2019, 03:14:20.021	fake redis read	Registry
Server	Session / Transport	May 31st 2019, 03:14:20.249	serving_attempt_completed	Registry
TransportHTTPS-Server		May 31st 2019, 03:14:21.984	flask_finalize_processing	Registry
TransportHTTPS-Client		May 31st 2019, 03:14:22.071	http_got_response	TSO
Client	Presentation	May 31st 2019, 03:14:48.600	client_got_response	TSO
		May 31st 2019, 03:14:48.634	client_decrypted_response	TSO
	Application	May 31st 2019, 03:14:48.638	client_run_request_completed	TSO
TSO		May 31st 2019, 03:14:48.660	on_rmp_search_response	TSO

Table 5: Events generated during communication of VerificationNotification request over MQTT transport. Transport-specific events are highlighted.

Event-Emitting Class	OSI Layer	Time	Event Name	Actor
AMS -> Client	Application	May 31st 2019, 05:05:28.572	client_run_request_begin	AMS
Payloadfactory	Presentation	May 31st 2019, 05:05:28.573	client_run_args	AMS
TransportMQTT	Session / Transport	May 31st 2019, 05:05:28.574	mqtt_subscribe	AMS
		May 31st 2019, 05:05:28.584	mqtt_publish	AMS
		May 31st 2019, 05:05:31.930	mqtt_on_message	MGMS
		May 31st 2019, 05:05:31.931	mqtt_handler_found	MGMS
Server		May 31st 2019, 05:05:31.932	try_serving_request	MGMS
Payloadfactory	Presentation	May 31st 2019, 05:05:31.950	got_request	MGMS
MGMS	Application	May 31st 2019, 05:05:31.952	mgms_on_update_-verification_notification	MGMS
		May 31st 2019, 05:05:31.952	mgms_updating_-verification_notification	MGMS
MGMS -> FakeRedis		May 31st 2019, 05:05:31.953	fake redis write	MGMS
MGMS		May 31st 2019, 05:05:31.954	mgms_slot_state_change	MGMS
Payloadfactory -> FakeRedis	Presentation	May 31st 2019, 05:05:31.955	fake redis read	MGMS
Server	Session / Transport	May 31st 2019, 05:05:35.523	serving_attempt_completed	MGMS
TransportMQTT		May 31st 2019, 05:05:45.613	mqtt_publish	MGMS
		May 31st 2019, 05:05:45.670	mqtt_on_message	AMS
		May 31st 2019, 05:05:45.671	mqtt_unsubscribe	AMS
Client	Presentation	May 31st 2019, 05:05:45.684	client_got_response	AMS
		May 31st 2019, 05:05:46.013	client_decrypted_response	AMS
	Application	May 31st 2019, 05:05:46.013	client_run_request_completed	AMS
AMS		May 31st 2019, 05:05:46.470	on_verification_notification_response	AMS

standard ways to generate Smart API payload objects using abstract packet definitions, that can be set up in configuration file (payloadstructure.yaml) using human-readable format of data representation. The structures defined in the configuration file are used to format requests from client to server, guaranteeing that the data is provided in the way, that is expected by the server. On the other side of the communication the configuration defines a number of standard endpoints, that can be populated with callbacks to server-side functions. Such functions can serve as both input and output points for data and signal streams.

The code, presented in Figure 10 describes structure of Smart API objects for both Request and Response, related to the same type of request (in this case Bid-type) under Structure sub-key. Nodes of the tree, located under this key are either Smart API concepts such as Entity or ValueObject, their possible attributes like Type, uniform resource identifier (URI), Name, Unit and Quantity or Special concepts of HEILA like QueryIterator, that assist construction of payload. In the case of QueryIterator - the purpose of this concept is to create lists of managed entities in the response using single entity template and a database query that returns a list of rows in comparison to a single row, that is expected otherwise. In addition to that Queries key defines relation of the Response to database query. In this case the query is defined under the name of QueryRedis, that uses database named FakeRedis (as defined in database.yml) and it will execute a call to getRedisBid member function of the class, that manages FakeRedis database (also defined in database.yml). The function is usually expected to return a row or a list of row of database records that result from query to database. The data, obtained from query is the substituted to the response structure using numerical mapping with ValueDbIndex parameters for ValueObjects. Finally for the server side the structure defines a callback function tag, that will be used to signal server class about new request and, which is supposed to process the request and write necessary updates to the database before they could be used in creation of response.

Figure 11 presents a sample call to HEILA client, that will execute Bid request to TSO actor. Here, callback defines the function, that will handle response of server, payload_type defines the type of request to be used (should match the root key in payloadstructure.yml). Finally, the rest of parameters, that are passed to the run call are converted into a dictionary, that is used in parametrization of the request structure. In Figure 10 the list of required parametrization parameters is provided under Arguments key.

3.2.3 Metadata register

A generic model of decentralized machine-to-machine environment implies grid decomposition where each IoT system is considered as a part of a larger ecosystem of interconnections rather than just a single solution. In order to work in this architecture, autonomous systems require metadata registry that acts as a "phone book" and shares the information about the types of

```yaml
Bid:
    Request:
        Arguments:
            - server
            - entityname
            - slot
            - namespace
        Structure:
            - Entity:
                - URI: "{server}/Bid/{slot}"
                - Type: "{namespace}Bid"

    Response:
        HandlesRequestType: "{namespace}Bid"
        ResponsePreprocessor: updateBid
        Queries:
            QueryRedis:
                DB: FakeRedis
                QueryName: getRedisBid
                Arguments:
                    - URI
        Structure:
            - QueryIterator:
                 Name: QueryRedisElement
                 FromQuery: QueryRedis
            - Entity:
                - Type: "{namespace}Bid"
                - URI: "{URI}"
                - ValueObject:
                    Name: ID
                    DataType: "{namespace}string"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 0
                - ValueObject:
                    Name: Type
                    DataType: "{namespace}string"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 1
                - ValueObject:
                    Name: Power
                    Unit: "{namespace}Watt"
                    Quantity: "{namespace}ActivePower"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 2
                - ValueObject:
                    Name: Start
                    DataType: "{namespace}dateTime"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 3
                - ValueObject:
                    Name: Stop
                    DataType: "{namespace}dateTime"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 4
                - ValueObject:
                    Name: Price
                    Unit: "{namespace}Euro"
                    Quantity: "{namespace}Price"
                    QueryName: QueryRedisElement
                    ValueDbIndex: 5
```


Figure 10: Example of payload structure for Bid-type request.

```
tso_connections[tso].run(payload_type="Bid",
                         callback=lambda x, s = self: s.on_bid_response(x),
                         myIdentity=self.rmp.my_identity,
                         server=tso,
                         entityname="",
                         slot=self.slot_id,
                         namespace=NS.SMARTAPI)
```

Figure 11: Example of Bid-type request performed by reserve marketplace (RMP) actor.

data, services, and control capabilities the other systems possess as well as requirements for their access. The metadata registry deploys functionalities of semantic web to discover the virtual representations of the devices based on the semantic meaning of these representations and their interconnections. The same idea is realized in HEILA metadata registry for autonomous interactions between the HEILA management systems. In the case of HEILA actors, these representations include exposition of their capabilities, properties, and types that are transformed to the machine-readable knowledge about them. Consequently, the registry provides vital semantic metadata to enable automated discovery of HEILA systems with required parameters for corresponding energy services.

There are two general types of registry services, which can be described as "white" and "yellow" pages. The former ones assume that the actor discovery is based on the semantic type of the actors, while the the latter ones rely on service-oriented discovery. HEILA metadata registry adopts the actor-based search to enable system interactions for different services. Every system in the platform follows sequential actions that could be purposely divided into "Register", "Search", and "Access". During the "Register" part, HEILA systems aim to become visible in the environment by sending a registration request to the registry with own metadata information. The basic metadata contained in such requests include namespaces, actor type, interface information, and its public key (PK). However for some systems as microgrid management systems (MGMSes), it also consists of services they provide, type of the resource they manage, and maximum power available for the services. The example of registration request for MGMS with "MGMSRegistration" entity is presented in Figure 12. The metadata in the request is semantically described with resource description framework (RDF) data model predominately with Smart API ontology which was internally enriched for the platform testing purposes by new entities. These entities are mostly related to the anticipated organization and terminology of decentralized smart grid architecture. RDF is encoded in Turtle format but can be also converted to JavaScript object notation for linked data (JSON-LD) or RDF/extensible markup language (XML). The adopted metadata for system description is not an exhaustive but rather minimum required for the interactions in HEILA platform environment.

```
@prefix ns1: <http://smart-api.io/ontology/1.0/smartapi#> .
@prefix ns2: <http://data.nasa.gov/qudt/owl/qudt#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

ns1:MGMS a ns1:Entity,
        ns1:MGMSRegistration ;
    ns1:manages [ a ns1:Battery, ns1:Entity ;
        ns1:valueObject [ a ns1:ValueObject ;
            rdfs:label "Power"^^xsd:string ;
            ns2:quantityKind <http://data.nasa.gov/qudt/owl/quantity#Power> ;
            ns2:unit <http://data.nasa.gov/qudt/owl/unit#Kilowatt> ;
            rdf:value 10 ] ] ;
        ns1:valueObject [ a ns1:ValueObject ;
          rdfs:label "PublicKey"^^xsd:string ;
          ns1:dataType ns1:string ;
      rdf:value """-----BEGIN PUBLIC KEY-----
rMIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAtuEY8MMCjDo5G8NFnAxorKF
VkqIVMSKoyloXXTFi0+qjYdAlSjebZUiF8gT60kaeFriMfHpwWZ/InJBXdL+merT8hHQ4Kyk2
wh0klgORfvQk6nAaCYcvLOopnEvJFISHXG7vCK0TVZm+StZrGeoMEErSnmLGQDXuQfvwr
92kirtao8MOf1Jj1taQFsFf90R/qF90YU1ftT1WbCPPcxTfT3WrAFPIIfCbima+/vsbmdMFPCj
xBlYPRu/Y/30jSbAAtqx7AAhqLarVagovNhMGm5L+rIDcXZmymvsDEk9suZxkhKant1VzZT
z1t2uglclOnkCsPFy3bQjQRZ4UkSNP2f+m9riQIDAQABr-----END PUBLIC KEY----""" ],
        [ a ns1:ValueObject ;
          rdfs:label "Host"^^xsd:string ;
          ns1:dataType ns1:string ;
          rdf:value "https://datahub.pc.lut.fi/mgms" ],
        [ a ns1:ValueObject ;
          rdfs:label "Path"^^xsd:string ;
          ns1:dataType ns1:string ;
          rdf:value "/LUT/demo/test" ],
        [ a ns1:ValueObject ;
          rdfs:label "Interface"^^xsd:string ;
          ns1:dataType ns1:string ;
          rdf:value "https://datahub.pc.lut.fi/mgms/LUT/demo/test " ],
        [ a ns1:ValueObject ;
          rdfs:label "Service"^^xsd:string ;
          ns1:dataType ns1:string ;
          rdf:value "FCR-N" ],
        [ a ns1:ValueObject ;
          rdfs:label "Signature"^^xsd:string ;
          ns1:dataType ns1:string ;
          rdf:value "" ].
```

Namespaces
Energy resource
Public key
Interface
Service type
Signature

Figure 12: MGMS registration request.

At the searching stage, the metadata serves as the basis for filtering the systems with specific types. The search is built by sending a request filled with required parameters, and, in the case of "AMSSearch" request presented in Figure 13, this required parameter is only the type of the system. The expected response will return the stored data of the corresponding systems registered at the moment of the request. An example of such response is illustrated in Figure 14. Finally, having received the registry response, the requester can leverage the data and query the other systems implementing the "Access" part.

```
@prefix ns1: <http://smart-api.io/ontology/1.0/smartapi#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

<file:///AMSSearch/https://datahub.pc.lut.fi/mgms> a ns1:AMSSearch,
    ns1:Entity .
<http://smarteg.org/reference/1.0/seas#8fddc928-5405-4dfd-86d5-7cb9e0d07dff> a ns1:Activity ;
    ns1:encryptionKeyType ns1:PublicKey ;
    ns1:entity <file:///AMSSearch/https://datahub.pc.lut.fi/mgms> ;
    ns1:method ns1:Read .

<https://datahub.pc.lut.fi/mgms> a ns1:Activity .

[] a ns1:Request ;
    ns1:activity <http://smarteg.org/reference/1.0/seas#8fddc928-5405-4dfd-86d5-7cb9e0d07dff> ;
    ns1:generatedAt "2019-05-14T06:06:59.878098"^^xsd:dateTime ;
    ns1:generatedBy <https://datahub.pc.lut.fi/mgms> .

, text/turtle; charset="us-ascii"
```

Figure 13: aggregator management system (AMS) search request.

```
@prefix ns1: <http://smart-api.io/ontology/1.0/smartapi#> .
@prefix ns2: <http://data.nasa.gov/qudt/owl/qudt#> .
@prefix rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#> .
@prefix rdfs: <http://www.w3.org/2000/01/rdf-schema#> .
@prefix xml: <http://www.w3.org/XML/1998/namespace> .
@prefix xsd: <http://www.w3.org/2001/XMLSchema#> .

[] a ns1:Entity, ns1:AMSSearch ;
ns1:valueObject
[ a ns1:ValueObject ; rdfs:label "Path"^^xsd:string ; ns1:dataType ns1:string ; rdf:value "/LUT/demo/test" ],
[ a ns1:ValueObject ; rdfs:label "PublicKey"^^xsd:string ; ns1:dataType ns1:string ;
rdf:value """-----BEGIN PUBLIC KEY-----\r\r
MIIBIjANBgkqhkiG9w0BAQEFAAOCAQ8AMIIBCgKCAQEAtuEY8MMCjDo5G8NFnAxo\r\r
KFVkqIVMSKoyIoXXTFi0+qjYdAlSjebZUiF8gT60kaeFriMfHpwWZ/InJBXdL+me\r\r
T8hHQ4Kyk2wh0klgORfvQk6nAaCYcvLOopnEvJFISHXG7vCK0TVZm+StZrGeoMEE\r\r
SnmLGQDXuQfvwr92kirtao8MOf1Jj1taQFsFf90R/qF90YU1ftT1WbCPPcxTfT3W\r\r
AFPIIfCbima+/vsbmdMFPCjxBlYPRu/Y/30jSbAAtqx7AAhqLarVagovNhMGm5L+\r\r
IDcXZmymvsDEk9suZxkhKant1VzZTz1t2uglclOnkCsPFy3bQjQRZ4UkSNP2f+m9\r\r iQIDAQAB\r\r
-----END PUBLIC KEY-----""" ],

[ a ns1:ValueObject ; rdfs:label "URI"^^xsd:string ; ns1:dataType ns1:string ; rdf:value " https://datahub.pc.lut.fi/ams" ,
[ a ns1:ValueObject ; rdfs:label "Interface"^^xsd:string ; ns1:dataType ns1:string ; rdf:value "
https://datahub.pc.lut.fi/ams/LUT/demo/test" ],
[ a ns1:ValueObject ; rdfs:label "Host"^^xsd:string ; ns1:dataType ns1:string ; rdf:value " https://datahub.pc.lut.fi/ams" ] .
```

Figure 14: AMS search response.

3.3 Actor modelling

Since the main objectives of the first version of the HEILA platform were mostly related to the data exchange, internal operation and functionality of the different actors were not the main focus, and development regarding these can be continued in following projects. Meanwhile, the actors in the present version of the platform were modeled using state-machine based approach with only baseline functionality. The state-machine simulated sequential logic of the actors as continuous transition between the actor states. The actors incorporate some attributes of reactivity, proactiveness, and social abilities. Most of the state transitions are provoked by actor reactions to changes that occur in the platform. The examples of these changes can be a time condition or received request of the other actor. Also, pursuing their design objectives, some actors proactively initiate some of the interactions using their social abilities. However, in the conditions of restricted intelligence, the proactiveness of these interactions is initiated in a rule-based fashion.

The HEILA actors corresponding to the implementation use case actors were implemented leveraging Actor Base and Slot Base classes. The Actor Base class implements generic methods for the actors while the Slot Base class is in charge of the actor actions for a specific time slot. The generic methods of the Actor Base include handling register, search, and access routines as well as performing thread and time-based routines for given slots and updating active slot handling objects with respect to the current time. The Slot Base class incorporates basic requirements to time slot and processes state transition on time tick. The state transition actions are predetermined by the design objectives of the actors in particular implementation use case and performed by Slot Handler class of each actor. An example of the slot sequential logic for the AMS Slot Handler in FCR implementation use case in presented in Figure 15 and is explained in what follows. When the AMS Slot Handler is initialized by AMS actor class for a hourly time slot, it requires the forecast of Fingrid FCR price for its hour from AMS to change its state. In the Hourly Market Prices Obtained state, the AMS Slot Handler can be up to 5:30 hours before the referenced bidding time to the RMP actor. If the time condition is passed, the AMS Slot Handler starts querying MGMSes found by AMS during the registration phase for flexibility entities. The transition for the next state is performed if all of the flexibility entities are obtained or the time before the bidding is less than 3:00 hours. Having proceeded to the next state, the AMS Slot Handler prepares the offer to submit to the RMP actor. If the offer is calculated, the AMS Slot Handler goes to a state number 6 and is waiting for the request from the RMP actor. Having received the request and posted the offer, the AMS Slot Handler progresses to an Offer Posted state. Subscribing to the reserve notification in this state, the AMS Slot Handler achieves the requirement for a transition to the next state where it is waiting for the reserve notification to be published by the RMP actor. Having received the notification, the AMS Slot Handler forwards it to the MGMSes that shared flexibility entities and is consecutively moved to a state number 10. In this state, the AMS Slot Handler is in idle state until the time after the end of the reserved time slot is exceeding 30 minutes. Then, the AMS Slot Handler subscribes to a verification notification from the MGMSes that were reserved for FCR service transitioning to a state number 12. If all of the required verification notifications are received by the AMS Slot Handler, it reaches the end of its sequential logic.

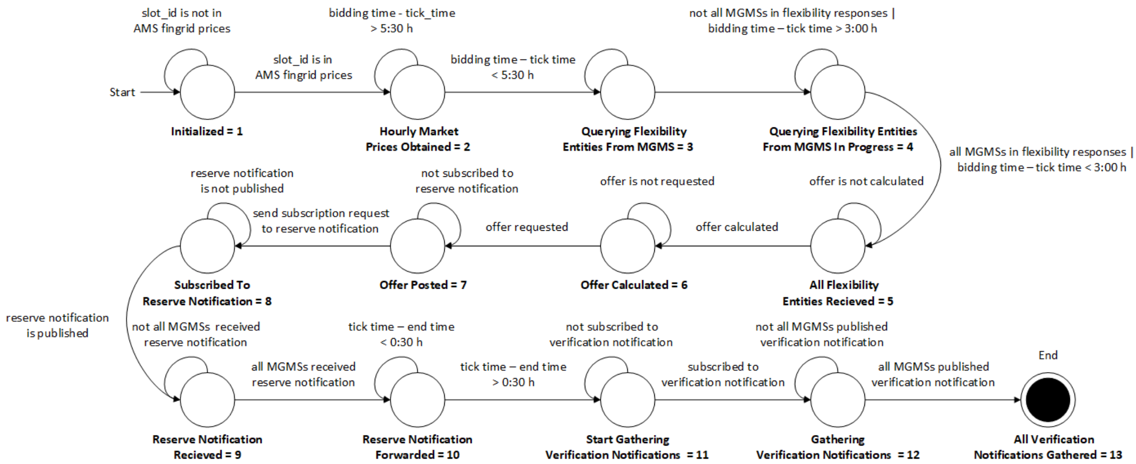

Figure 15: An example of AMS Slot Handler state transition.

3.4 Cybersecurity

Cybersecurity is one of the key aspects that needs to be properly addressed when novel concepts are applied in real-life systems. The main issues addressed in this implementation of system are access control, data authenticity and data malleability.

The access control is ensured by multiple layers of encryption of the communication. At the outer level the data is encrypted with TLS defined for HTTPS and MQTT protocols, that are used as transports. Inside the payload the segments of data, that communicate useful information are encrypted using hybrid encryption where the payload is encrypted by symmetric unique advanced encryption standard (AES) key and the key itself is encrypted asymmetrically with Rivest–Shamir–Adleman algorithm (RSA) PK of the party to which the message is intended. Such encryption also partially addresses the issue of authenticity as any response can only be decrypted by the holder of the corresponding private key. The exchange of information about PKs happens through requests to Registry actor for which the PK is preshared for all participants. This approach minimizes the risk of man-in-the-middle type of attacks and the only major weak point is potential leak of Registry PK. This, however can be addressed by use of multiple Registries with independent public-private keys. Finally, data malleability is also addressed by used encryption algorithms.

The payload encryption is implemented with asymmetric key encryption scheme and described in Figure 16 based on the interactions of Registry and the other Actors. At the initial step illustrated in Figure 16 by 1 where every Actor has received preshared Registry PK in addition to its own asymmetric key pair. Then, when Actor is sending the register request, it encrypts the registration payload with the Registry PK. Having received Actor register request, registry decrypts it with own private key, if the registration is successful, it returns the registration acknowledgement encrypted with Actor PK. Moreover, in order to communicate with other Actors, each of the

Actors requests other Actor search from Registry. As a response to such request, the registry sends to the Actor the found Actors' metadata and attached to them keys pairs that are further used by the Actor to interact with filtered actors. For instance, if Actor A receives request from Actor B it cannot decrypt the request payload until it fetches the Registry for corresponding Actor key. Thus, this mechanism of environment interactions via the registry extends the role of the registry as a trust authority by provision of encryption key management.

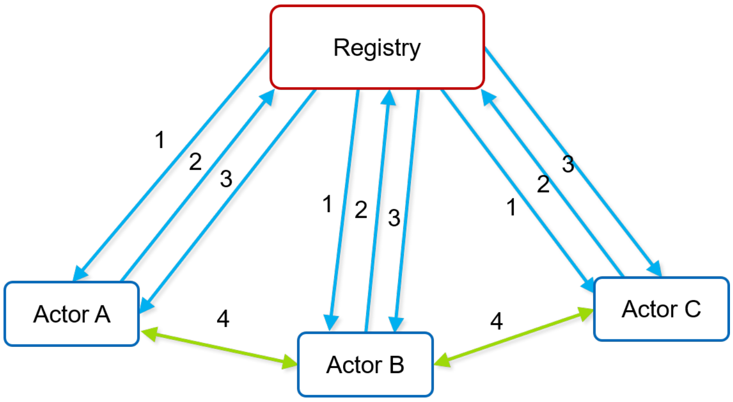

Figure 16: Registry encryption key management: 1- Preshared Registry PK; 2 - Registration request with actor's own PK; 3 - Query PK of other actors; 4 - Asymmetrically encrypted communication.

Further improvements to the cybersecurity that are yet to be implemented and which will continue to reduce security risks are: use of session and message-specific numbers used once (nonces) which will reduce possibility of replay attacks and generation of digital signatures for payloads to improve data authenticity.

3.5 Datawarehouse

The data warehouse is essential part of the HEILA demonstrations platform as it serves development of the platform but also showcasing of the results. During HEILA project demonstrations, all test results are collected with logs to centralized Kibana data warehouse. This way it is easy to follow how actors in different sites are operating throughout the tests, get a good general view for whole system and gather specific test results. It should be, however, noted that in business use of the data exchange platform, all data does not need to be gathered to a centralized place.

The data warehouse implementation is based on software stack called Elasticsearch, Logstash, and Kibana (ELK) stack [20] providing features from log data ingestion to versatile querying and visualisation of the log data. The Logstash provides an open source serves side data processing pipeline that ingest data from varying data sources and forward transformed data to Elasticsearch [21]. Elasticsearch provides search interface to utilize multitenant-capable full-text search engine with an HTTP web interface and schema-free JavaScript object notation (JSON) documents.

Finally, topmost software Kibana [22] serves as a user interface to enable easy visualisation of the log data.

In practice, ELK stack implementation in HEILA environment offers centralised logging service that enables easy logging and log management. HEILA environment offers Python module to remotely ingest logs to ELK stack implementation from each demo site. Log messages include variety of metadata in addition to timestamp to enable effective analysis based on the log evens. Figure 17 illustrates simple example view of the Kibana dashboard. In the figure number of successful verification notification is presented as a list but also as a user-friendly graph.

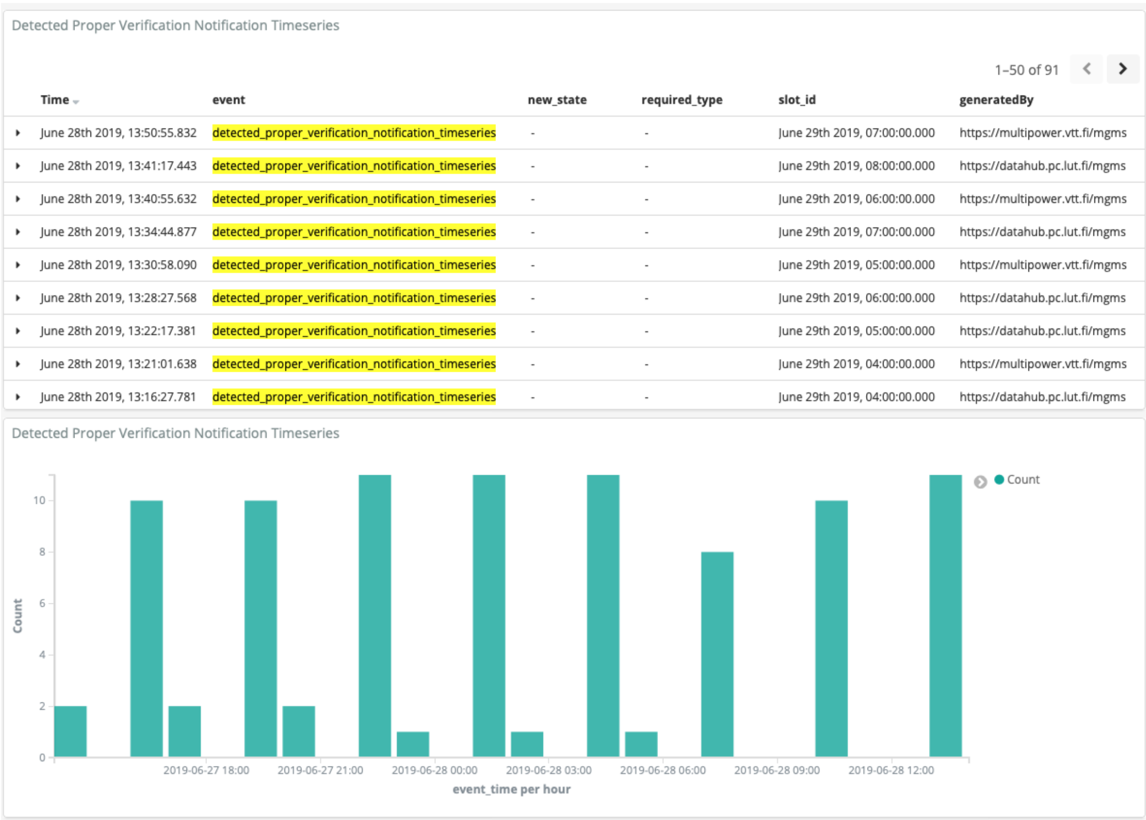

Figure 17: Example illustration of the Kibana dashboard.

4 Demonstrations

Two use cases have been selected to be demonstrated in HEILA project as already described in section 2. The selected use cases are DSO flexibility and FCR. Monitoring use case is a part of both the selected demonstration/implementation use cases. The selection criteria was such that the demonstration use cases should represent situations where functionalities provided by such data exchange infrastructure as the HEILA platform would be needed in real business cases. The selected use cases require monitoring and control of DERs at various locations. Also, microgrids and their effect on system operation is a topical research question.

The aim of the demonstrations is to implement and test the operation of the HEILA platform and its applicability for the selected use cases. The HEILA platform has two main purposes of use:

- Providing a testing platform for test cases that cannot be implemented in one laboratory or pilot site. The testing platform can be used for research and development purposes and enables system-level testing that has not been possible before HEILA. It can be utilized by the project research partners but also by companies in further projects after HEILA.
- Providing a first prototype of the data exchange infrastructure that can be used in the future smart grid to connect also small-scale resources as a part of system operation.

Demonstrations verify the correct operation of the platform, give information on its characteristics (e.g. transfer times) and reveal further development needs. The demonstrations provide also new information on how the selected use cases could be implemented. The implementation does not, however, constrain all the details but the HEILA platform enables also different types of message structures, use case sequences etc.

This section describes the demonstration set-up, initial Smart API testing and the three use case demonstration testing steps. At first, communication testing was conducted. At this stage, all messages were exchanged according to the use case sequence diagrams using Smart API and physical resources were simulated i.e. no real resources were included in testing. The second stage is open-loop testing where physical resources are included as a part of the test case and change their outputs based on either the frequency measurement (FCR use case) or on DSO control signal (DSO flexibility use case). However, measurements from the resources are not fed back to the network model and hence the loop is not closed. In closed-loop testing, there would be a virtual electrical connection between laboratories and the measurements from the real physical resources would be utilized in the real-time network simulation. In HEILA project, initial steps towards closed-loop testing were taken but the complete implementation will be left as future work.

4.1 Laboratories used in demonstrations

The pilot sites and laboratories utilized in demonstrations are provided by LUT, TAU and VTT. At the first phase, one site for each of the research partners is connected to the platform. These pilots are LUT Green Campus, TAU smart grid laboratory and VTT MultiPower laboratory. In the demonstrations, TAU's laboratory emulates part of the electrical grid using a real-time simulator and the laboratories of VTT and LUT operate as microgrids located at different parts of the system. The microgrids have controllable resources that are utilized to provide ancillary services to market places. The emulated actors and market places are located in the same three laboratories as the real-time simulator and the microgrids but are executed as their own entities and all data exchange goes through the developed information exchange platform similarly as in business use of the platform. Moreover, the locations of the different actors have been selected such that data exchanges in the selected test cases mostly happen between laboratories and not inside them. The metadata register is located in a fourth place. The laboratories and emulated actors and market places used in the demonstrations are represented in Figure 18 and the geographical distribution of different actors participating to the test cases in Figure 19. The distances between the different locations are hundreds of kilometers. This enables more realistic studies regarding utilizing the public internet as the information exchange channel.

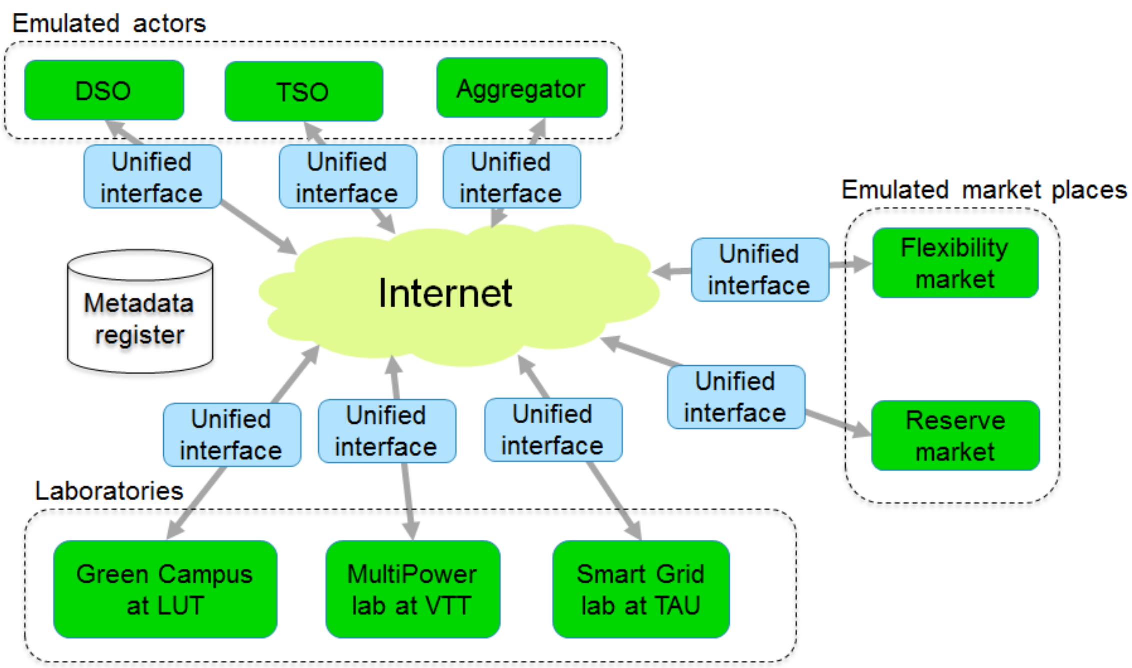

Figure 18: The implemented testing platform.

4.1.1 LUT Green Campus

The LUT Green Campus is an umbrella project of LUT that covers for instance the laboratory environment utilized to demonstrate a variety of microgrid functionalities in the power grids and the communication networks. The laboratory resources are located in Lappeenranta south-east

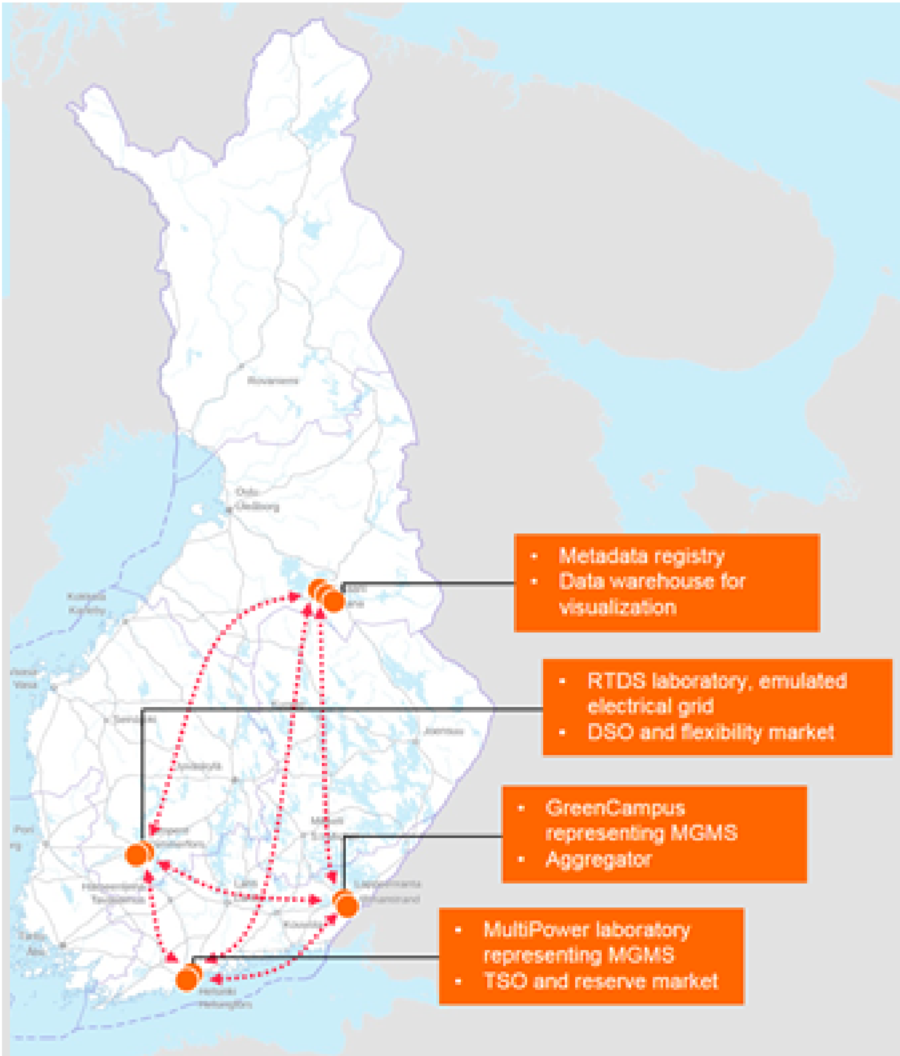

Figure 19: Actors and resources are geographically distributed.

Finland. The LUT Green Campus grid consists of a 132 kWh battery energy storage connected to an low-voltage direct current (LVDC) test network, 206 kWp of solar photo-voltaic (PV), 20 kW of wind power, a smart electric vehicle (EV) charging pole and several external data streams to enable novel control schemes. The laboratory setup has an extensive collection system for research data.

In the testing use cases controllable resources of the laboratory will be utilized as a part of larger system. The present laboratory setup provides highly flexible ICT resources to implement proposed communication interfaces and control schemes. The present system with battery resource enables functionalities such as local voltage regulation, reactive power compensation, frequency containment reserve, production and consumption peak shaving.

4.1.2 TAU Smart Grid Laboratory

TAU smart grid laboratory represents a distribution grid and Flexibility Market Platform in the demonstration. Real-time digital simulator (RTDS) or OpenDSS power system simulation tool is utilized as a backbone of the system to simulate the electrotechnical part of the complete system. Simulator analyses a distribution grid with connected DERs and microgrids in real-time or near real-time. Data can be exchanged between the resources located elsewhere (VTT and LUT) and simulated grid via the Internet. It is worth of mentioning that proposed system will not be utilized for transient performance studies, but rather for the analysis of interaction and cooperation of market participants. In addition a hierarchical and distributed distribution grid management solution as a DSO functionality for congestion management is also utilized in TAU's demonstration site [23]. The automation solution is based on prototype Substation Automation Units located at primary and secondary substations including data collection, storing, analysis and reporting capabilities, i.e. realizing hierarchical and distributed grid automation system. The details of laboratory are described in reference [24]. The unified interfaces (Smart API) are installed for the Substation Automation Unit and for the Flexibility Market Platform. Those are running in a Linux personal computer (PC) with Ubuntu operating system.

4.1.3 VTT MultiPower

VTT's MultiPower laboratory located in Espoo is a combination of multiple independent testing facilities that can be connected together if required. The whole laboratory environment contains different types of generation, load and storage units as well as measurement, control and protection systems. At the first phase, only a part of the laboratory is connected as a part of the developed business platform through the information exchange interface. The connected testing facility consists of a low-voltage (LV) network which contains a micro-scale PV unit, a PV emulator, resistive and inductive loads and a connection point for external devices. Also a grid emulator is available enabling controlling voltage and frequency of the laboratory network. Measurement, control and protection systems contain environmental measurements for the PV system, ABB COM600 grid automation controller, four ABB REF615 feeder protection Intelligent Electronic Devices (IEDs) and a global positioning system (GPS) time synchronization server.

In the test cases that will be used to demonstrate the operation of the developed information exchange platform, the MultiPower laboratory can be used to represent either an individual resource or a microgrid.

4.2 Initial implementation results

The implementation work has started with Smart API development. This section describes the results of the first tests and the next steps in implementation are described in subsections 4.3, 4.4

and 4.5.

4.2.1 Smart API testing

Very first communication tests with the Smart API included sending and receiving hard coded measurement value between different organizations. HTTP server/client and MQTT broker/client combinations were utilized in the first tests. Figures 20 and 21 present the test setup and message for the first tests.

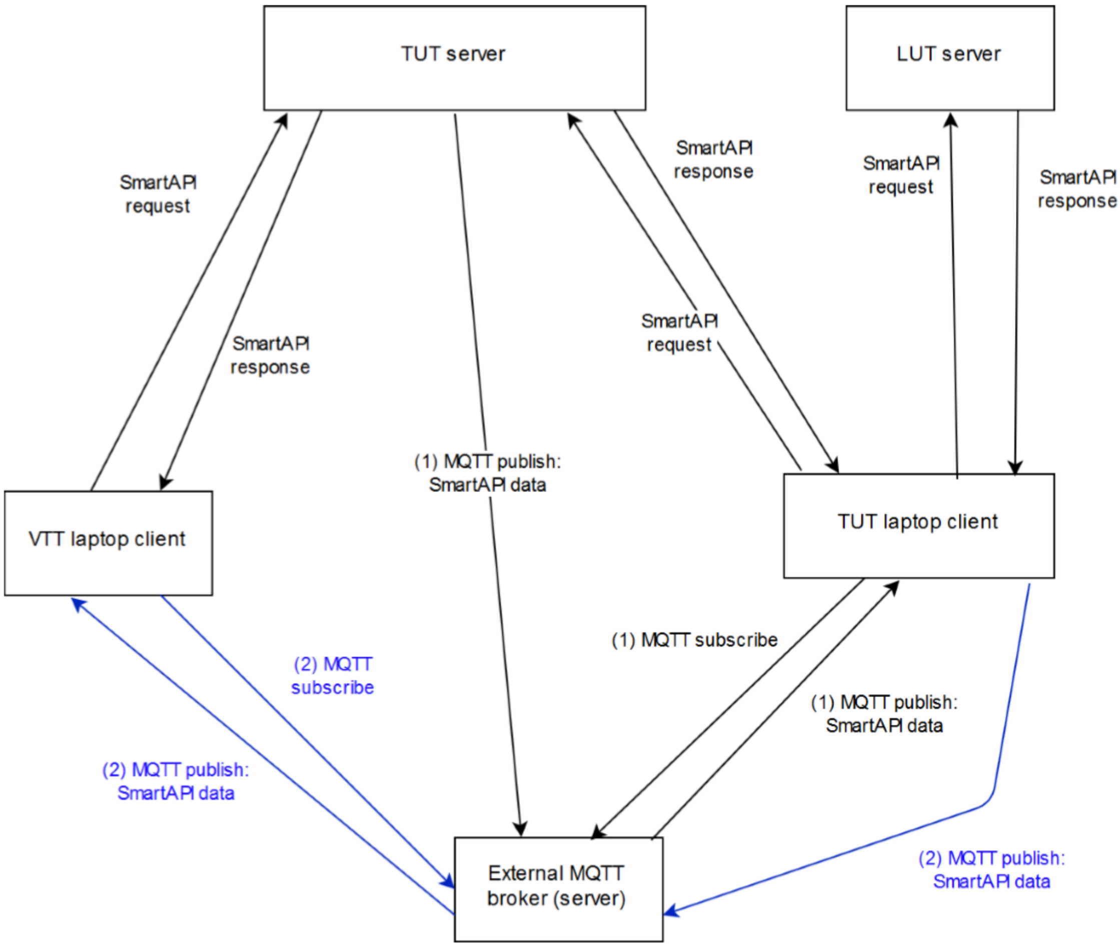

Figure 20: Smart API communication test setup.

First communication tests were successful as different organizations were able to send and receive messages when Smart API operated as interface. In this phase referring to common information mode (CIM) resources was also demonstrated.

4.2.2 First on site implementation

First tests on site included sending and receiving use case (DSO Flexibility) related messages between actors and controlling process on site. Figure 22 illustrates interfaces 1-3, which were part of this phase, and test setup. In comparison to Smart API testing phase, this time also local database was utilized, messages were use case related, messages included more complex

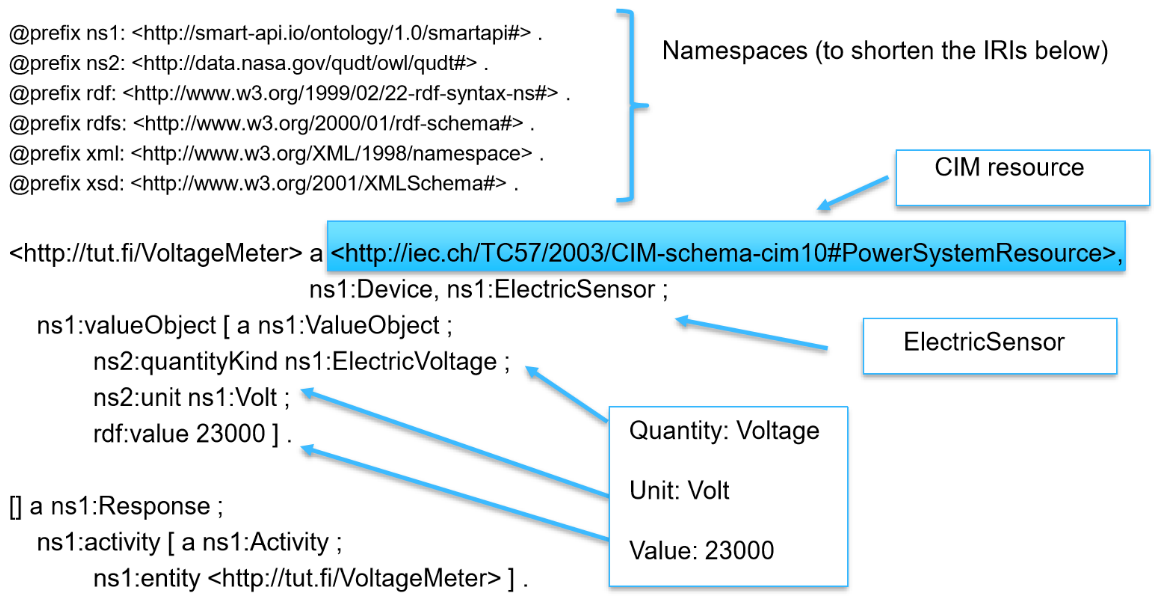

Figure 21: Message structure for Smart API communication test.

information, process on site was controlled and transfer times were gathered. Furthermore, from DSO Flexibility use case parts where MGMS sends Flexibility information to AMS and later receives Activation Notification, which leads to a control command, from AMS were part of this phase.

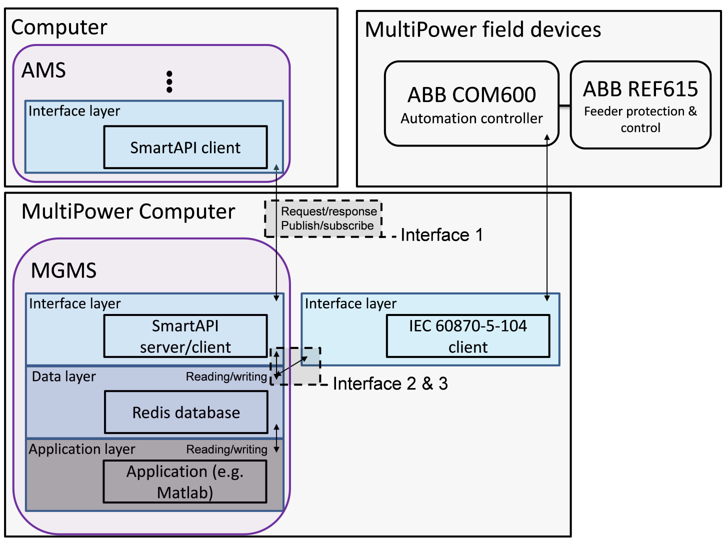

Figure 22: MultiPower test setup.

First on site implementation was successful as sending and receiving use case related messages and controlling process were possible. In addition, transfer time results provide supplementary information about system performance. Table 6 presents average transfer times with 10 attempts for different messages in the tests. In this phase, CIM references were not utilized.

Table 6: Average transfer times with 10 attempts.

Monitoring direction			
Message and route	**Flexibility, AMS database ← MGMS database**		**Feeder phase voltage, MGMS database ← REF 615**
Protocol	HTTP	MQTT	IEC 60870-5-104
Transfer time (ms)	47	52	483
Control direction			
Message and route	**ActivationNotification, AMS database → MGMS database**		**Feeder JK-T.KK-TL3 circuit breaker position, MGMS database → REF 615**
Protocol	MQTT		IEC 60870-5-104
Transfer time (ms)	36		584

4.3 Communication testing

In communication tests, proper operation of all actors is verified and test results are collected by running test cycles continuously. Test objective is evaluation of transfer times of communication between the actors. Tests results are collected with logs to centralized data warehouse 'Kibana'. This way it is easy to follow how actors in different sites are operating throughout use case test cycle, get a good general view for whole system and gather specific test results.

In one test cycle, all actors are registered and discovered to/from registry and encryption keys are delivered in first 30 minutes. Then, all messages are exchanged according to use case sequence diagram and use case reaches its final state well before test cycle period (3 hours of real time) ends. This allows updates between test cycles if needed. Furthermore, simulated time is used in FCR use case. Simulated time passes faster than real time so it is possible to run multiple test cycles in a single day. In addition, physical resources are simulated (using battery energy storage system (BESS)) or measurements of a physical resource (IED) are forced to certain values during communication testing to allow unsupervised testing. Figure 23 illustrates tests setup for FCR use case.

4.3.1 FCR use case

One FCR test cycle operates 20 hours in simulated time and 3 hours in real time. FCR test sequence (use case) starts by setting simulated time to 4 pm of current day and delivering flexibility information from different sites to aggregator before 6.30 pm. Before 10 pm aggregator and TSO form offer and bid, RMP requests them and notifies both about reserved products. Then,

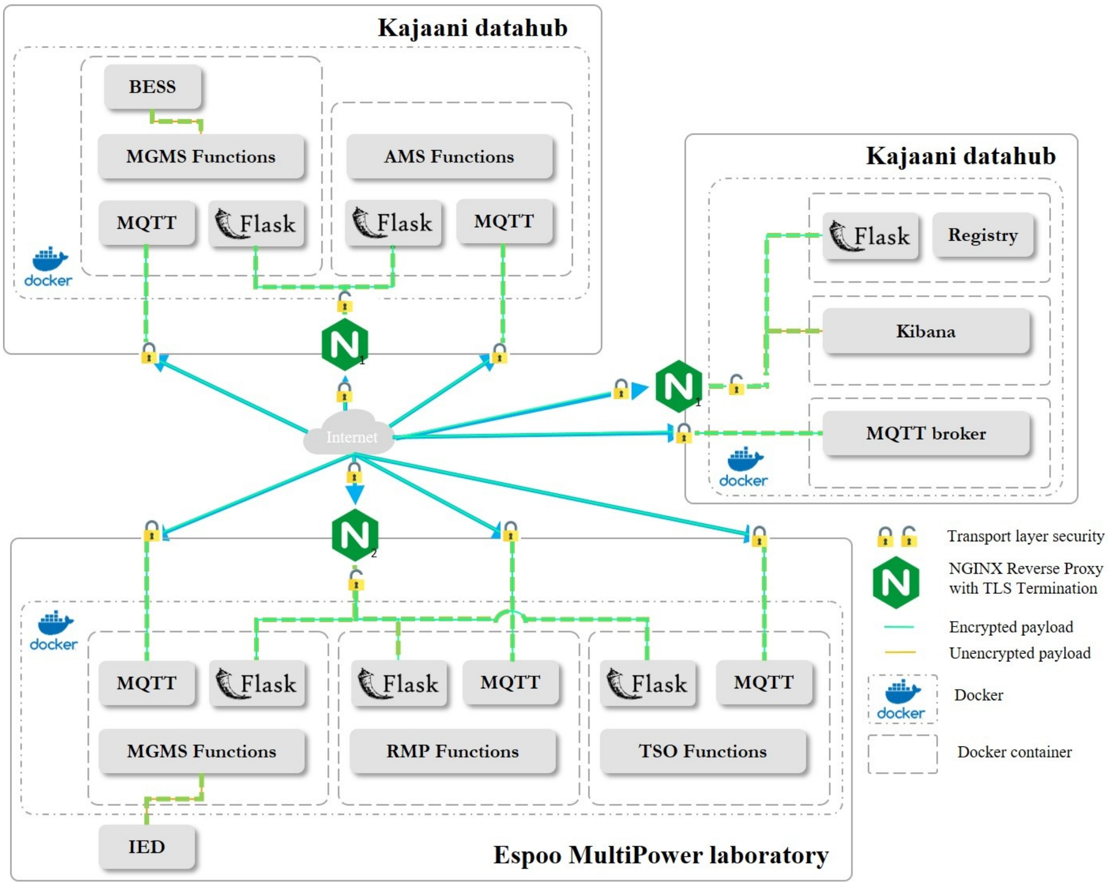

Figure 23: Communication test set-up for FCR use case.

aggregator notifies MGMSes about reserved products, which in turn modify operation plan of resources they are managing for accepted hours. At midnight, first operating hour starts and different sites perform autonomous FCR-N control. After operating hours, different sites deliver product verification information to aggregator that gathers them for later use.

In communication tests, logs are gathered in several steps for each of messaging protocols. This allows investigation of different parts of messaging sequence in case of both protocols. Figures 24 and 25 present communication test results for HTTP and MQTT protocols over 6 test cycles and 18 hour period.

As presented in Figure 24 HTTP communication test results are presented from situation where HTTP client (Actor B) sends POST request to Flask (Actor A) up to a point where HTTP client (Actor B) completes requesting activities. Total time for the whole messaging sequence varies from about 1,5 to 148,5 seconds. Time for the whole message sequence is about 78,6 s when looking at points where percentage first time deviates from 100% level. Highest values 89,1 and 25,1 seconds are at message sequence parts 2 and 6, respectively. It should be noted that in part 2 times are affected by fact that currently Smart API calls are synchronized. Moreover, in

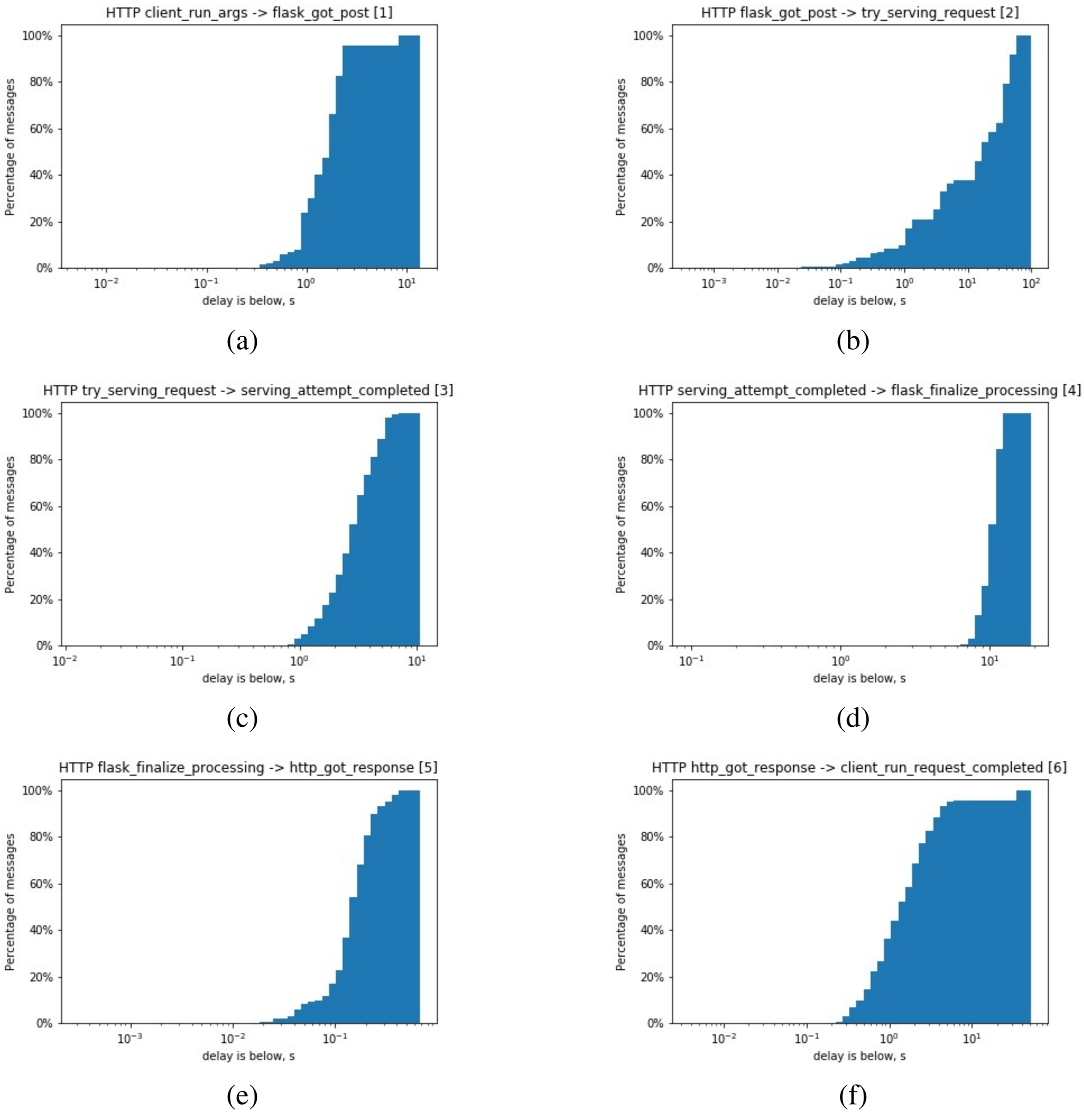

Figure 24: HTTP communication testing results

part 6 times are affected by retrying requests in cases where respond is not something what was expected, for example if respond was empty. When looking at times of parts 5 and 6 where a respond is transferred from Actor A to Actor B times vary between about 0,15 and 25,4 seconds and that includes possible retries.

As can be seen from Figure 25, communication test results for MQTT are presented in similar way that for HTTP. Total time for the whole messaging sequence varies from about 11,3 to 1 hour 5 minutes and 43 seconds. Highest values 3548,1 and 158,5 seconds are at message sequence parts 4 and 2, respectively. It should be noted that in part 4 times are affected by fact that if Actor B sends a request to Actor A, then Actor A can withhold respond until requested information is ready. So, in case of FCR use case, AMS can send Verification Notification request to MGMS well before operating hour starts and MGMS can respond just after operation hour is over and all

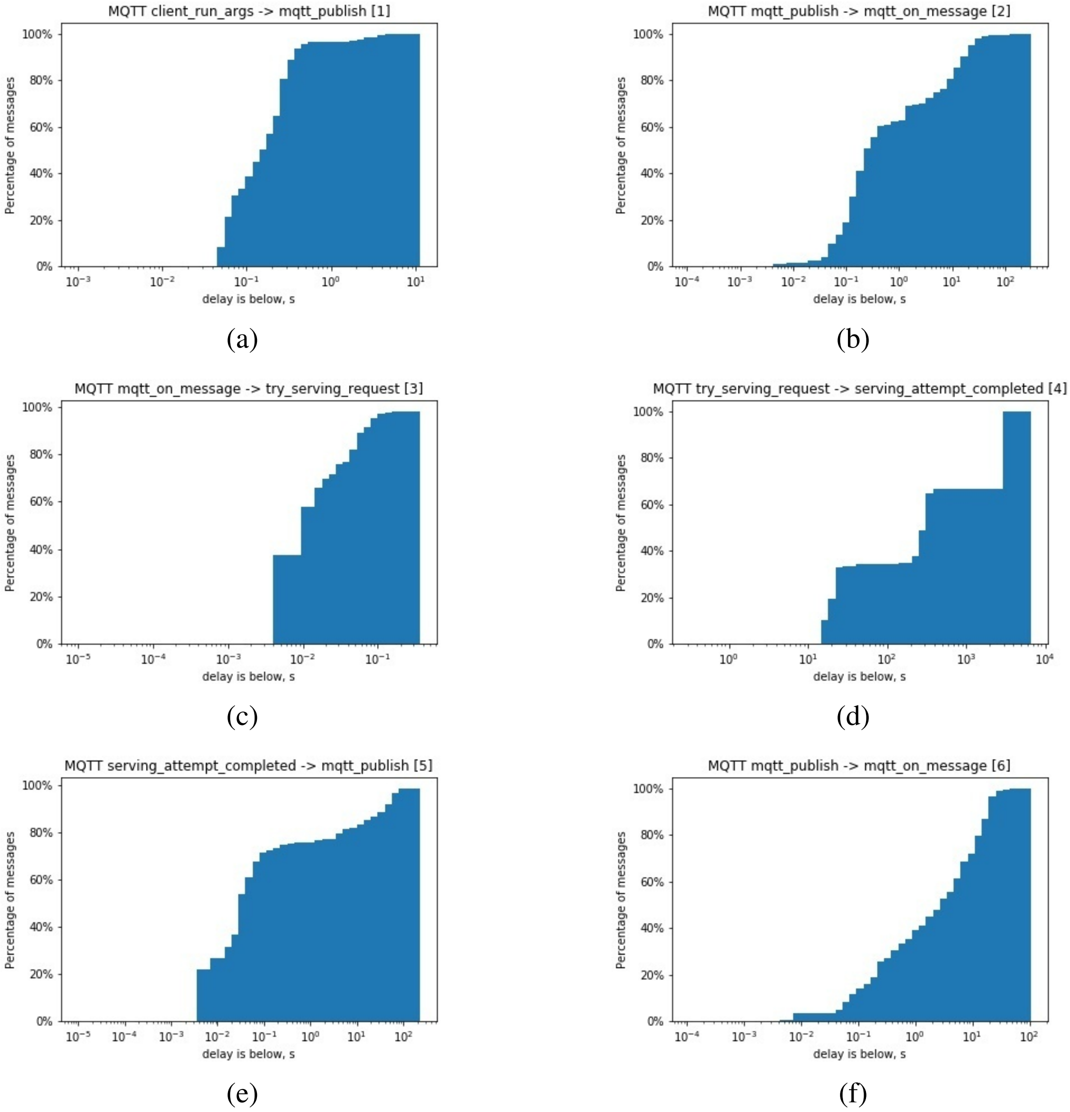

Figure 25: MQTT communication testing results

required measurement information is available. Furthermore, in part 2 times are affected by the fact that currently Smart API calls are synchronized. When looking at times of part 6 where a respond is transferred from Actor A to Actor B times vary between about 2,5 milliseconds and 100 seconds. Now AMS and MGMS at Kajaani datahub locate on same computer as MQTT broker, which can lead to very small transfer times and again, synchronization of Smart API calls affect maximum times on part 6.

4.3.2 DSO flexibility use case

In the initial plan, DSO Flexibility test cycle operates 3 hours in real time. DSO Flexibility test sequence (use case) starts by delivering flexibility information from different sites to aggregator in 10 minutes. In next 10 minutes aggregator forms offers, flexibility market platform (FMP) requests them and delivers offerings information to DSO. Next, between 20 and 30 minutes from start of the cycle, DSO sends bids for suitable offers to FMP, which in turn notifies aggregator and DSO about reserved products. Then, aggregator notifies MGMSes about reserved products, which again modify their operation plan for accepted hours. After one hour from the beginning of the test cycle, operating hour starts and aggregator waits that DSO notifies it to activate reserved products. If aggregator receives activation notification, it conveys message to different sites, which will operate their equipment accordingly. After operating hour, different sites deliver product verification information to aggregator that gathers them for later use. The DSO flexibility use case was tested partially. Information exchange between laboratories utilizing Smart API was not been able to finalize. However, DSO's internal information exchange was completed.

Figure 26 represents the implementation of DSO and FMP parts of DSO flexibility use case. There are three computers in TAU lab: substation automation unit (SAU), FMP and OpenDSS as shown below. The OpenDSS engine is used for simulating electric power distribution network containing substations, medium voltage feeders and power sources, i.e. it represents the real physical power system for the testing environment. The OpenDSS computer is also capable of exchanging data with SAU via HTTP server (Apache HTTP server). HTTP client at SAU computer sends a HTTP message with XML payload to HTTP server at OpenDSS computer to request the status of distribution network. The same message may include also information if some control variables (reactive power setpoint of generator, on-load tap changer setpoint or active power curtailment of generator in this case) is requested to change in simulation model. In reality this request would generate multiple messages, because some of them flow to distribution automation and others flow to aggregators providing flexibility for a DSO. HTTP server set new setpoints for the simulation model of OpenDSS Engine and will receive simulation results as a response. HTTP server sends further the requested measurements data (voltage, active power, reactive power, etc.) to HTTP client at SAU computer.

SAU computer includes the intelligent part of DSO decision making. PostgreSQL database is utilized as an integration and storage element between different interfaces and internal functionalities. In the database, one table is created for measurement and setpoints data. Every time HTTP client reads server data, it inserts data to the table in database. The HTTP server also provides timestamp for the data, which is also inserted to the measurement and set points table. So, different interfaces and functionalities may read the most recent data values from the table by sending the respective structured query language (SQL) queries to the database. HTTP client requesting data from OpenDSS reads new setpoints from the database and it writes the received measurement values to the database. In similar way the internal functionality (optimal power flow (OPF) functionality) read and write values from/to database. OPF solves an optimal solution periodically. In this use case the optimal solution includes minimization of grid losses and curtailed generation while network congestion (overcurrent, overvoltage and undervoltage) needs to be avoided. The OPF solution is realized by inserting updated setpoints to database which HTTP client will read and send to corresponding controllers (controllers in OpenDSS simulation model in this case). Information exchange with external interface implemented by Smart API is also realized with SQL read and write. Smart API interface exchange information with FMP, which further exchange information with other market participants of the use case. From SAU computer perspective, it does not see the difference between simulated environment (simulated distribution grid in OpenDSS and simulated market in FMP) or real system and therefore the testing of SAU's functionalities is feasible in the integrated laboratory environment.

The conclusions of DSO flexibility communication testing are such that all interfaces work correctly, information exchange utilizing SQL database and HTTP client/server is appropriate for the use case, and coordination and synchronization of events may be realized with SQL database and communication delays. Simulation of events and responses which are slow enough is feasible, if at least one OpenDSS simulation solution (preferably more) is available for the next round of functional sequence of use case. Artificial information exchange delays may be added when those are critical/interesting for the performance of the functionality. Abstraction of DSO functionality, simulation tool, FMP, microgrid functionality, etc. enables easy modification of each of them (loosely coupled subsystems) and opens possibility for multiple kind of combinations in testing.

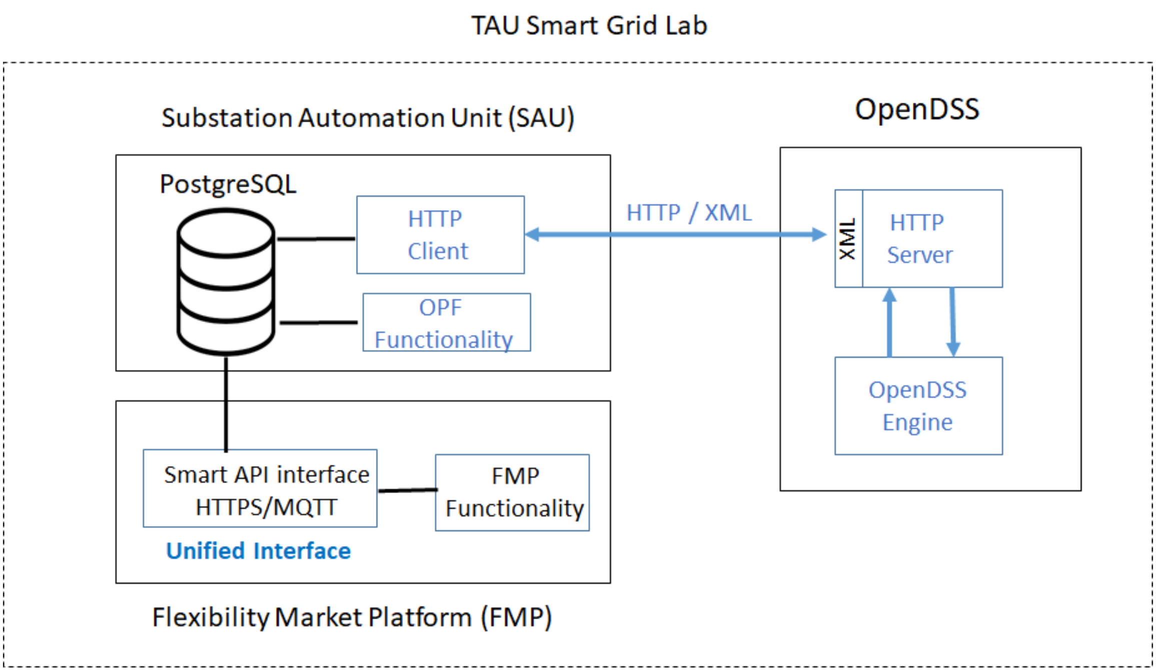

Figure 26: Information exchange between SAU and OpenDSS.

4.4 Open-loop testing

Open-loop testing has been implemented on the basis of the structure, described in the previous chapter (communication testing). The major difference is that, instead of simulated DER, the real hardware has been connected to the system to be controlled by HEILA MGMS actors.

On LUT side that connection has been established through an intermediate IEC104 Master software, that provided HTTP API with the ability to provide controlled device with a task for individual 6-minute long intervals. Each task can be either: "Idle", "Charge", "Discharge" or "Manual". During the idle task the battery maintains 0 Active Power reference, while during charge and discharge the active power is constant 10 kW charging or discharging respectively. Finally, during manual task the controlling system provided a preset active power curve with 1s resolution that defined the active power response of the system with 1 kW granularity for each second of the upcoming 6-minute interval.

On VTT side the hardware connection has been established through an intermediate Modbus connection with the ability to provide control signals (operation mode) for ABB COM600 grid automation controller, which controls IEDs in the MultiPower laboratory. Operation modes in FCR use case can be “Normal” or “FCR”. In operation mode “FCR” the COM600 monitors grid frequency and disconnects/connects load with threshold value of 49,95 Hz. Due to restrictions on available devices in the MultiPower lab, the load is disconnected/connected as whole instead of step-wise operation that would follow current rules on FCR market. In addition, grid emulator feeds the low voltage network inside the MultiPower laboratory and controls frequency according to Figure 28.

On TAU side DSO grid is simulated in RTDS or OpenDSS. Grid simulation combines all laboratories together electrically although they are physically located in different places without direct electrical connection. Microgrids in LUT and VTT in addition to other grid components are modelled in RTDS or OpenDSS, but the status and control of them is realized based on decisions made in HEILA platform. In open-loop testing the control loop is not completely closed. For example, when DSO makes an activation request to microgrids in DSO flexibility use case, the corresponding activation message is delivered to microgrids and forwarded directly to simulator. In closed-loop testing, the electrical parameters of microgrids in RTDS/OpenDSS simulation would be changed based on actual measurements. Open-loop testing assumes that activation happens as requested within specified time (a communication delay may be added). The benefit of open-loop testing is to avoid/minimize delays and synchronization problems of virtual simulation environment, which does not exist in real-life. Open-loop testing may be utilized for use case functional testing to verify correct operation of use case implementations. Detailed testing of technical performance would require closed-loop testing environment.

Another essential part of TAU’s laboratory is the Substation Automation Unit shown in Figure 27. Substation automation unit is an advanced distribution automation solution based on hierarchical and decentralized decision making. It is capable of e.g. autonomous congestion management in distribution grid at very local area (e.g. in low voltage network) if needed. DSO functionalities are implemented in Substation Automation Unit that contains PostgreSQL database for storing monitoring and forecast data required for local decision making (predicting congestion, requesting flexibility services, utilizing DSO's own or contracted resources, and activating flexibility services). Database will deliver bids and activations to Smart API for information exchange between TAU, VTT and LUT laboratories. Activation messages are also forwarded via Socket or manufacturing message specification (MMS) client to RTDS simulation.

FMP emulates the market place utilized for congestion management including detailed location information about flexibility resources. The information exchange between Substation Automation Unit, FMP and other actors is realized via information exchange platform (HEILA Smart API). From DSO's perspective DERs and microgrids are controlled indirectly via market. Modified version of congestion management concept presented in reference [25] will be utilized in the demonstration.

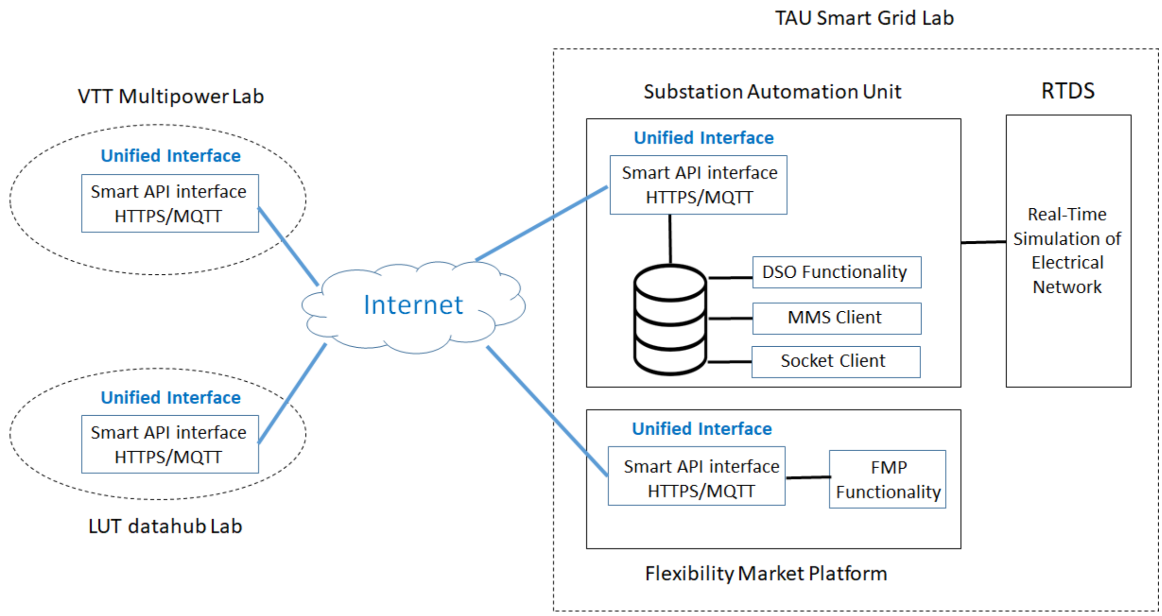

Figure 27: TAU smart grid lab.

4.4.1 FCR use case

Test objectives. The objective for FCR open-loop testing is to test the whole use case and verify that the physical resources operate as expected i.e. power changes according to the component characteristics when frequency changes.

Test description. In this use case the hardware resources were considered procured by TSO for FCR. The frequency signal, that was used as reference has been predefined from historical data on the basis of having significant deviations from the nominal grid frequency (Olkiluoto event from June 2018). 6 hours of frequency data has been selected and pre-shared between laboratories. The 3-second average curve of frequency, used in testing is presented in Figure 27.

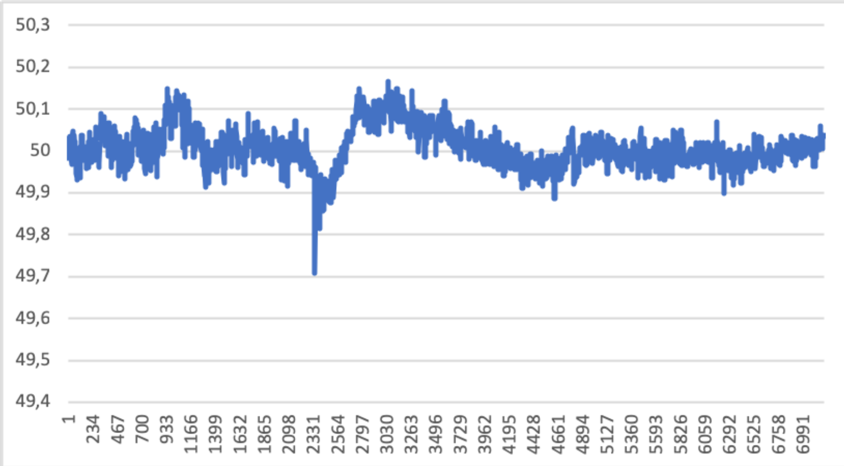

Figure 28: The frequency sequence used in FCR open-loop tests.

The MultiPower and GreenCampus laboratories represented microgrids in the test set-up and one controllable resource was utilized from both laboratories. At GreenCampus, BESS was selected and at MultiPower a controllable load was used. The BESS at LUT was operated according to a droop curve. Due to some restrictions in MultiPower equipment during the testing period the load was controlled in a way that differs from the current FCR rules. The MGMS in the MultiPower connected/disconnected a single load with certain threshold value. The test sequences were accelerated with respect to real life scenario to decrease the amount of time needed for testing.

Test outcomes. Both communication and open-loop tests were successfully conducted and verified that the data exchange platform concept and implementation operate as expected and that it was possible to include real hardware in the testing. Some deficiencies in the test set-up were detected and will be dealt with in future work. Some open-loop test results from MultiPower are represented in Figure 29 and from GreenCampus in Figure 30.

In MultiPower, the frequency seen by the controllable load was produced by a grid emulator to which the frequency sequence was fed through a Modbus interface. There were some issues with this interface and, therefore, the frequency in the lab did not follow the sequence exactly. Luckily, in cases where the frequency goes below the threshold value the grid emulator was operating correctly. Furthermore, the figure illustrates clearly that load is disconnected if frequency is below the threshold value.

In GreenCampus, the MGMS calculated a power set point for the battery based on the frequency sequence. The BESS output measurements indicate that in general the battery was able to track

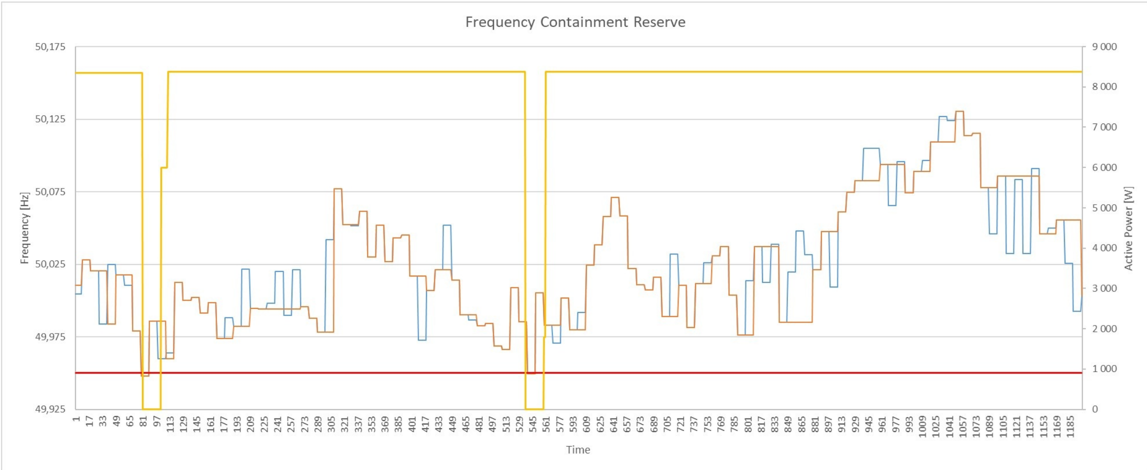

Figure 29: Open-loop testing results from MultiPower. Power measurement of the controllable load (yellow), frequency threshold to disconnect/connect the load (red), predefined frequency sequence (blue) and the frequency seen by the load (orange).

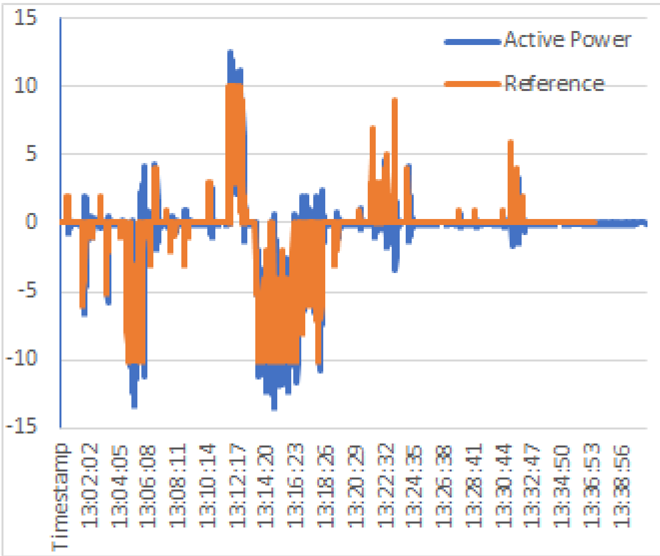

Figure 30: Open-loop testing results from GreenCampus. Delivered active power measurements on output of BESS. Vertical axis is in kW.

the provided reference signal. This verifies that the communication of registration, market and control commands occurred in a timely manner despite the test sequence being accelerated with respect to real life scenario, where it would be operated in a real time. However, notable overshoots are present in the response signal of BESS. The potential causes for such behavior are imperfections in the measurement of active power or cable reflections, caused by sharp active power change fronts. Detailed analysis is to be conducted in order to establish the root cause which, however, does not directly relate to the subject of this research.

4.4.2 DSO flexibility use case

Test objectives. The objective for DSO flexibility open-loop testing is to test partial use case (DSO's internal operational part) and verify the functional performance of OPF functionality in distribution grid congestion situation.

Test description. Partial open-loop testing (DSO internal operational phase) includes the similar implementation than utilized in communication testing of DSO flexibility use case in subchapter 4.3.2. Tests do not include physical resources and initial part of the use case is also excluded. It is expected that market trading and closing has already happen, and therefore DSO know what flexibility resources, where and at what price has available for the operational phase. Distribution grid and it's response to control decisions is simulated in OpenDSS. Flexibility activation messages will be send to DERs and OpenDSS in the open-loop testing, otherwise the impact of flexibility activation would not be seen. In this test it is assumed that both flexibility offers from LUT and VTT microgrids would be needed based on DSO's predicions, and therefore the both bids would be accepted. It is further assumed that partial activation of bids (splitting of bids) is possible and acceptable for DERs and aggregators. Also offered bid volumes are enough to solve the predicted congestion together with DSO's own or contracted measures (on-load tap changer and reactive power control of generator). Production unit has non-firm connection contract with DSO, and therefore production curtailment is also possible measure for congestion condition. The cost of that is very high for the DSO, which makes it the least preferable option for congestion management.

Simulated grid is presented in Figure 31, which shows also a potential congestion condition in the grid (overvoltage in node 5 in the example). Green arrows in the figure represent the active power flow and blue arrows are the reactive power flow. Negative sign of reactive power of the generator means that generator is underexcited (consumes reactive power from the grid). The model includes representation of supplying grid (nodes 1 and 2), primary transformer and it's on-load tap changer (between nodes 2 and 3) and two medium voltage feeders. The first feeder has a generator in the end of the feeder and two loads. Microgrids at LUT and VTT are associated to those load points. The second feeder has one load point. In this case the congestion may appear as overvoltage in the first feeder due to generator feed-in, or as undervoltage on second feeder due to demand. Because over- and undervoltage problems may happen at the same time, the optimal solution for the problem is not trivial. Control variables for OPF functionality are tap position of on-load tap changer, reactive power of generator, flexibility activation from microgrids (conditional re-profiling (CRP) products), or production curtailment of generator. Controls have different costs for the DSO and previous control variables were listed from the cheapest to most expensive. Voltage should stay between 0.95 - 1.05 pu.

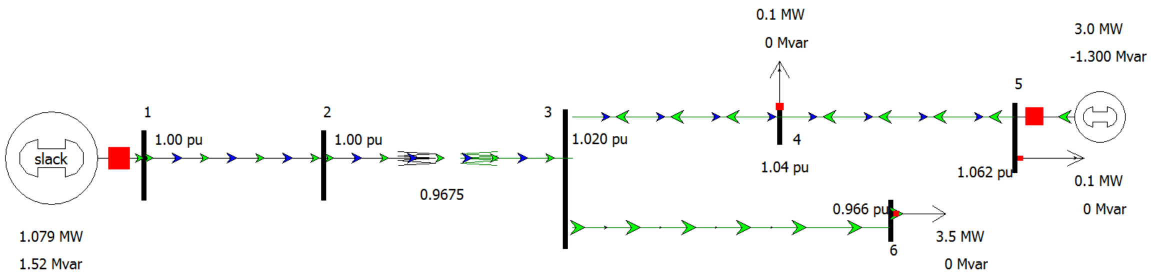

Figure 31: Simulated distribution grid and example of congestion condition in medium voltage feeder.

Simulation case includes the following sequence in time for the generator connected in node 5. Load demands remain constand for a sake of simplicity in the testing case, except when flexibility bids are activated. Utilized load demand are visible in Figure 31.

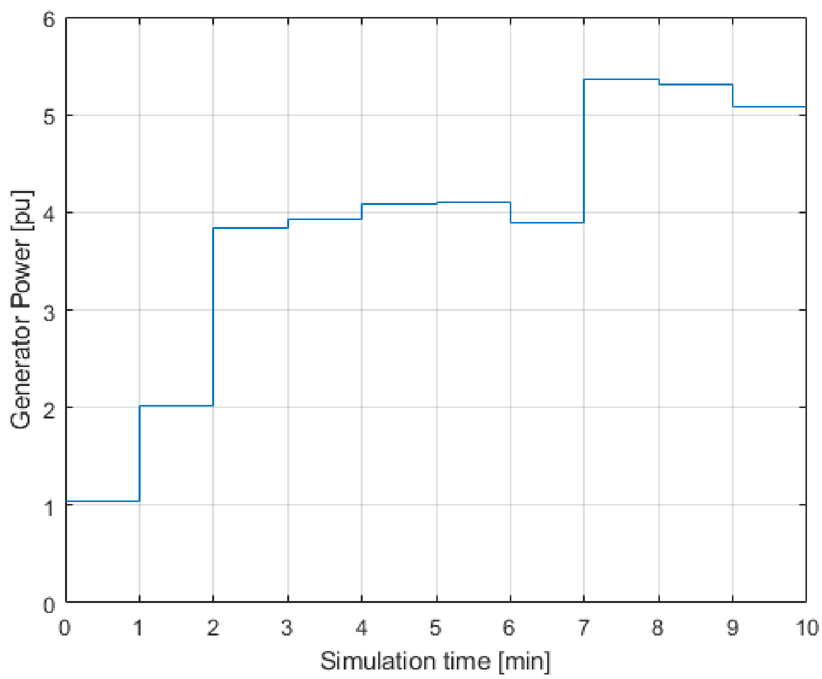

Figure 32: Generator timeserie for the simulation study.

First simulation sequence is run without any active control of the resources. Generator follows the defined generation curve and the loads are kept at their nominal values: 0.1 pu for nodes 4 and 5, and 3.5 pu for node 6. This serves as the base case for this test. The simulation results are depicted in figures 33 and 34. The nodal voltage results exhibit significant overvoltage in the generator node 5 and minor undervoltage in the large load node 6. The defined measure for voltage violations in this test is "over/undervoltage area", this metric is defined as the voltage exceeding the bounds integrated over time. Over and undervoltage areas in this simulation are 15.11 pu*s and 3.9 pu*s respectively. Grid losses are presented in Figure 34. Like it is very clear from the figure, losses are very much dependent on power flow condition. Grid losses are very close to zero between 2-7 minutes, when generator production is quite well in balance with total load in medium voltage network. After 7 minutes when the volume of production increases further, the grid loss increase too.

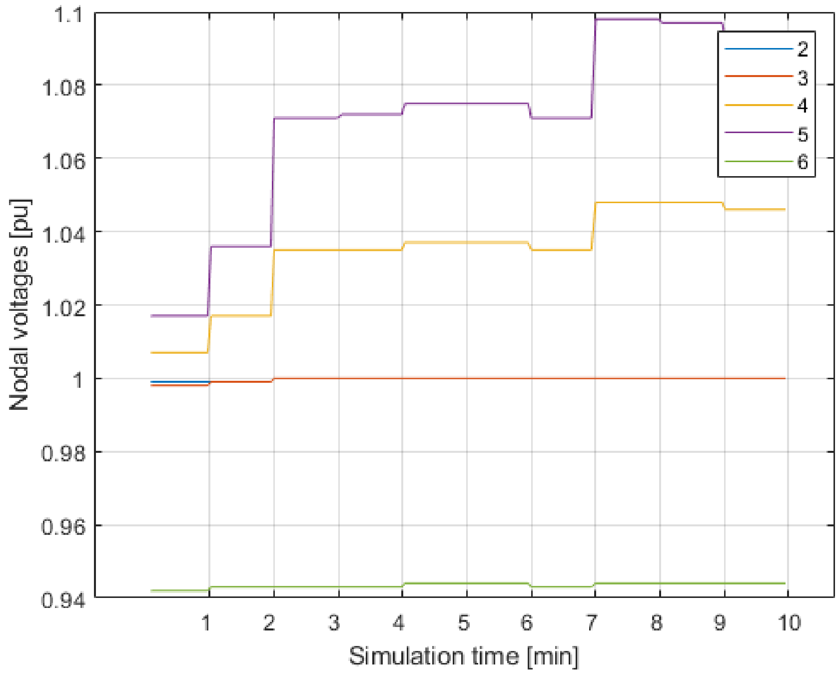

Figure 33: Nodal voltages without control.

Second simulation sequence is run with active control of the network resources. Again the generator follows the predefined timeserie, but its reactive power can now be controlled (between 0 and 1.3 pu inductive and capacitive). Also, the loads in the nodes 4 and 5 can be controlled between 0.1-1.5 pu and 0.1-2.6 pu. The simulation results are depicted in figures 35 through 37. On-load tap changer setting may also changed in order to optimize appropriate voltage level for node 3.

As can be seen, the voltage violations of the network are significantly reduced in comparison to the base case. Over and undervoltage areas in this simulation run are 0.825 pu*s and 0.2 pu*s. Overvoltages happen after sudden changes in the production, but after some time the control system is able to reduce the voltage level within acceptable limits without violating undervoltage limit. The delay in control is due to delays in how often OPF is running, on-load tap changer response time, and activation of flexibility bids.

However, the increased voltage quality comes with a cost, network losses are increased around 50%. Losses are increased compared to base case, because the power flow balance has been changed for less favorable direction by increasing load demand of microgrids (Figure 37) by

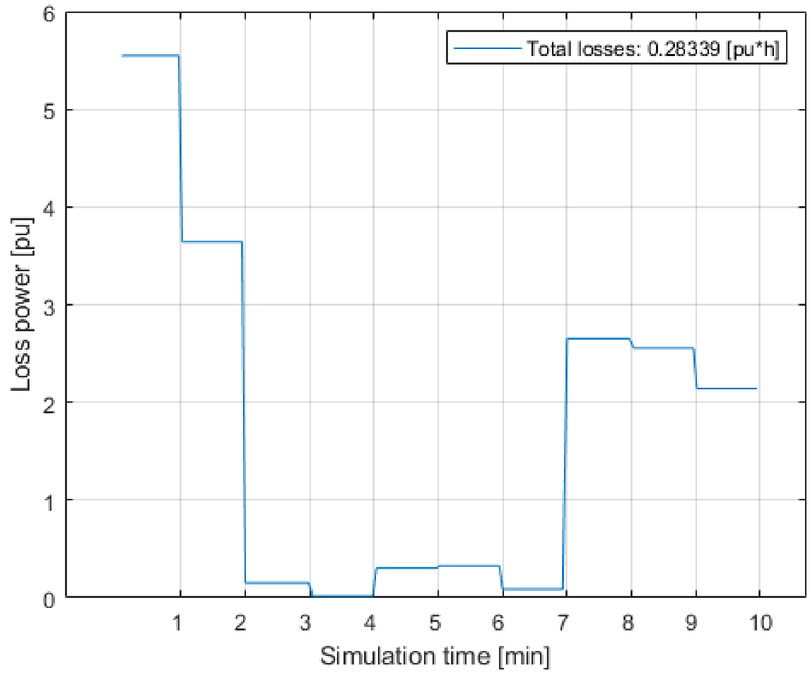

Figure 34: Network losses without control.

activating flexibility bids. Additionally, the flexibility required from the loads in nodes 5 and 4 is also significant. Production curtailment was not needed in this case.

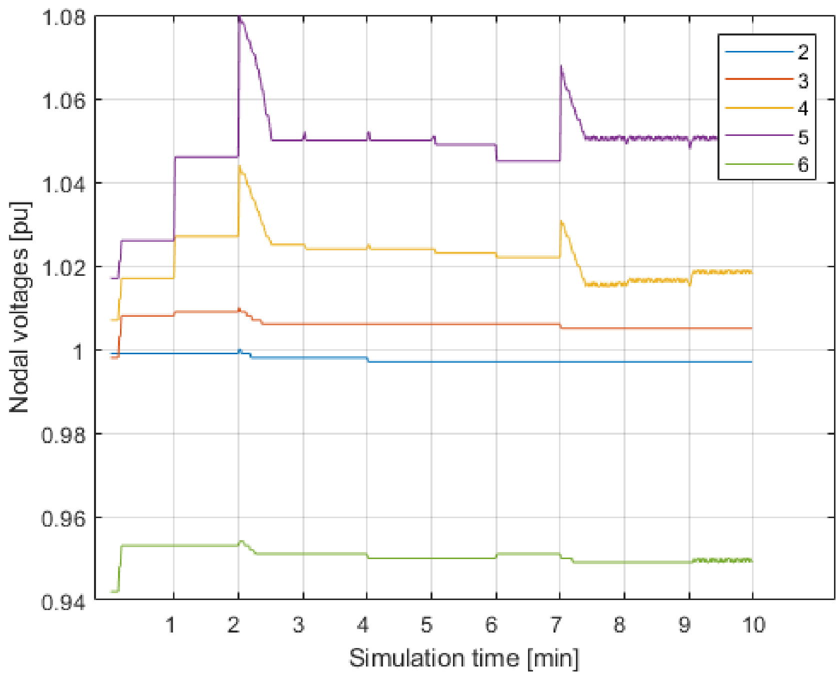

Figure 35: Nodal voltages with control.

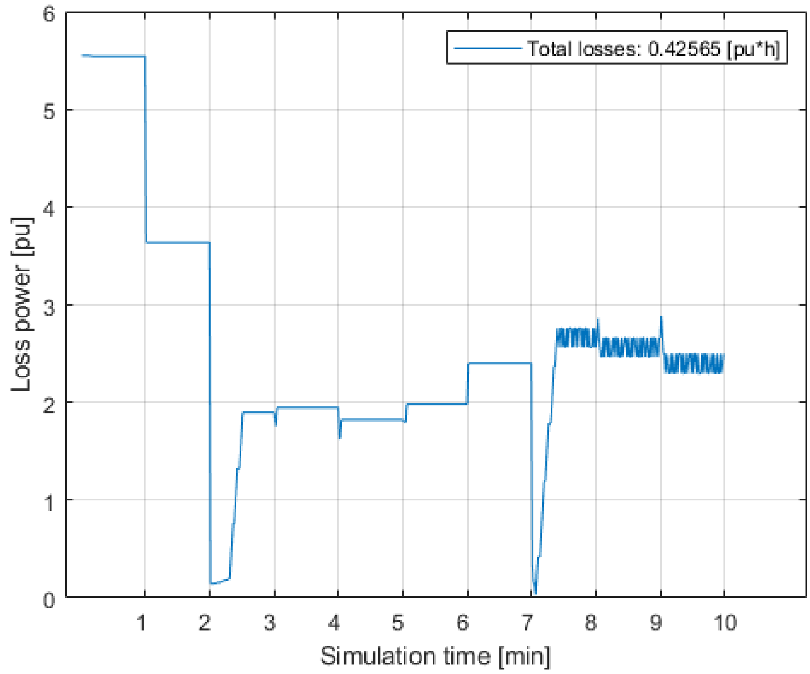

Figure 36: Network losses with control.

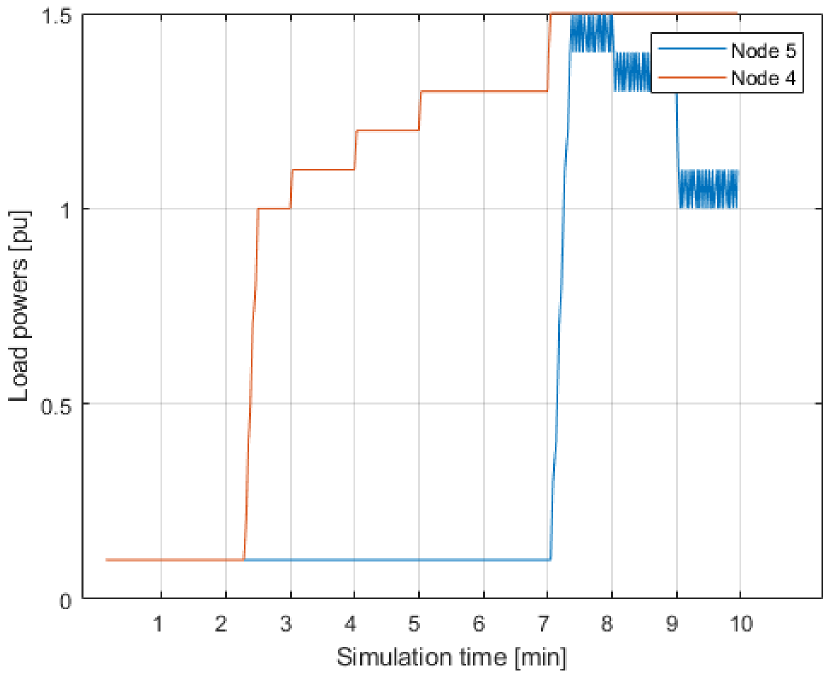

Figure 37: Load increases in nodes 5 and 4.

From functionality viewpoint, these simulation show the feasibility of utilizing the flexibility market in distribution network congestion management. Given an accurate state estimate of the network and availability of controllable resources, the system has a capability to dramatically reduce the voltage violations in the network, with the cost of additional losses.

4.5 Closed-loop testing

In closed-loop testing, the physical resources at LUT and VTT are completely included for the test. In closed-loop testing, a virtual electrical connection between the labs (TAU, VTT and LUT) is built by sending voltage and frequency measurements from the TAU RTDS to the microgrids located at LUT and VTT, measuring the real and reactive powers at these labs and closing the loop through feeding these measurements back to the RTDS network model.

This set-up requires minimal data transfer delays and, therefore, virtual private network (VPN) tunnel using user datagram protocol (UDP) traffic in order to minimize the communication latency was established for transferring signals needed for virtual electrical connection. The test was not implemented completely. In the current version, the test only includes remotely reading voltage and frequency (V&F) values from the simulated network model in RTDS. In the future version, VTT and LUT will be able to write the power and reactive power values (P&Q) to the RTDS model. However, the real-time virtual co-simulation has issues with the impacts of the variation in communication latency and the unsynchronized events during real-time simulation. A possible open source solution for these challenges has been detected (VILLAS framework for local and geographically distributed real-time co-simulation [26]), but it has not been tested yet.

The laboratories are equipped with firewalls that prevents unauthorized access from the public Internet. IPsec tunnel with certificate-based authentication was established between TAU, VTT and LUT laboratories. Consequently, secure communication path is created for information exchange between the laboratories. After satisfying the firewall requirements (open UDP port and internet protocol (IP) protocols), X509 digital certificates and private keys are created for IPsec VPN connection in each lab. The IPsec server is located in TAU, which can be accessed by the IPsec client in VTT and the client application developed at LUT, as shown in Figure 38.

First, IPsec client and servers in lab devices are authenticated by exchanging X509 digital certificates. After successful authentication, encapsulating security payload (ESP) provides confidentiality (encryption) and integrity (digital signature) for the exchanged IP packets between the laboratories (TAU, VTT and LUT). The advanced encryption standard with 256 bits digest (AES-256) and secure hash algorithm with 512 bits digest (SHA-512) standards applied for encryption and hash algorithms, respectively. An electrical distribution network containing voltage source, Primary substation transformer, medium-voltage (MV) feeders, Secondary substation transformer and loads are simulated in the RTDS. The RTDS has also support for adding different communication protocols to the simulated model. This requires adding a communication card to RTDS, which provides a real time communication to/from the simulator. In order to create IEC104 communication, the GTNET card with IEC 104 firmware (GTNET-IEC

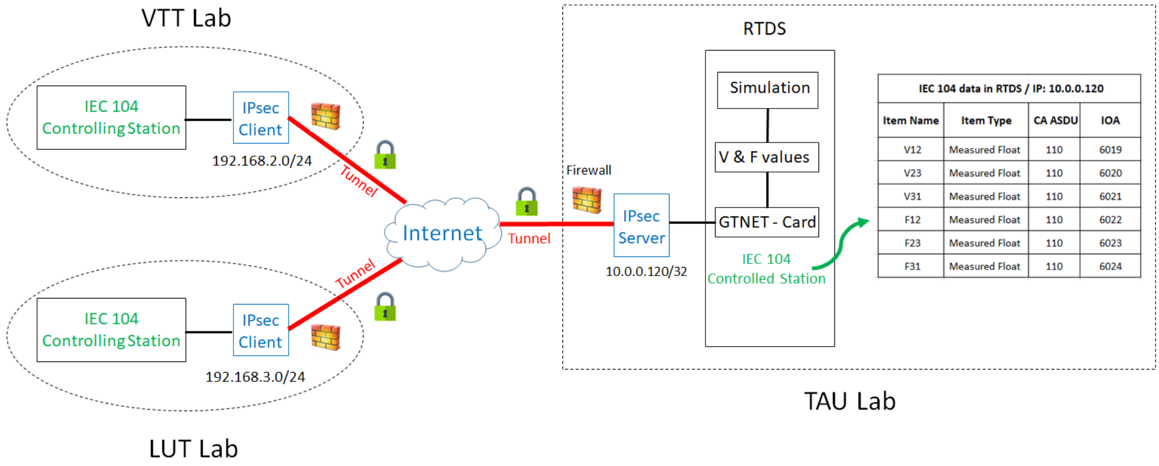

Figure 38: VPN Tunnels for the Closed-loop testing.

104) is added to the RTDS model. The GTNET card has Ethernet port and acts as the IEC 104 Controlled station that can be connected to the external IEC 104 Controlling station in VTT and LUT over the Internet. The GTNET-IEC 104 maps measurement data (Analog Status Points) to the IEC 104 Measured value, short floating point value M_ME_NC_1. Figure 38 also depicts the IEC 104 info, Common Address Application Service Data Unit (common address (CA) application service data unit (ASDU)) and information object address (IOA), for voltage and frequency values in the RTDS network model.

In order to test remote lab connection's latency, Ping messages with 800 bytes of data exchanged every 10 seconds between TAU lab and other labs (VTT and LUT) for the period of 24 hours. The average round-trip time delay was calculated for both with and without IPsec VPN connection. Figures 39 and 40 illustrate the average value of delay in each test, the statistical distribution of the round-trip times as well as each individual measurement of delay on time domain. In the figures, N is the number of ping messages that recorded during 24 hours period. The Ping messages that their transmission times was longer than 30 ms are also regarded as outliers.

The measurements of round-trip times show that communication latency is in acceptable level for closed-loop virtual co-simulation especially for market transaction purposes. It also shows that the communication part includes some uncertainties which are not controllable due to utilization of public Internet (Funet). There are also local communication issues which is visible while comparing measurements between TAU-LUT and TAU-VTT. If the longer average round-trip time to LUT is due to LUT internal configurations, then in principle this might be improved. However, the measurements are not realized on same day, which reduces the possibility to make clear conclusions. Especially the measurement for TAU-LUT without VPN is questionable. The time domain measurements show also step changes and two levels in round-trip time, which are most likely due to external traffic, which always exists, but reduces possibilities to compare the results reliably. Although the communication latency is rather short most of the time, it includes stochasticity and sometimes the latency might be many times higher than the expected value. This issue will impact how well the synchronization methods are able to synchronize event happening at the same time in different location but the information is received at different time. Due to the uncertainties associated to these results, further studies on the delays should be conducted at following projects.

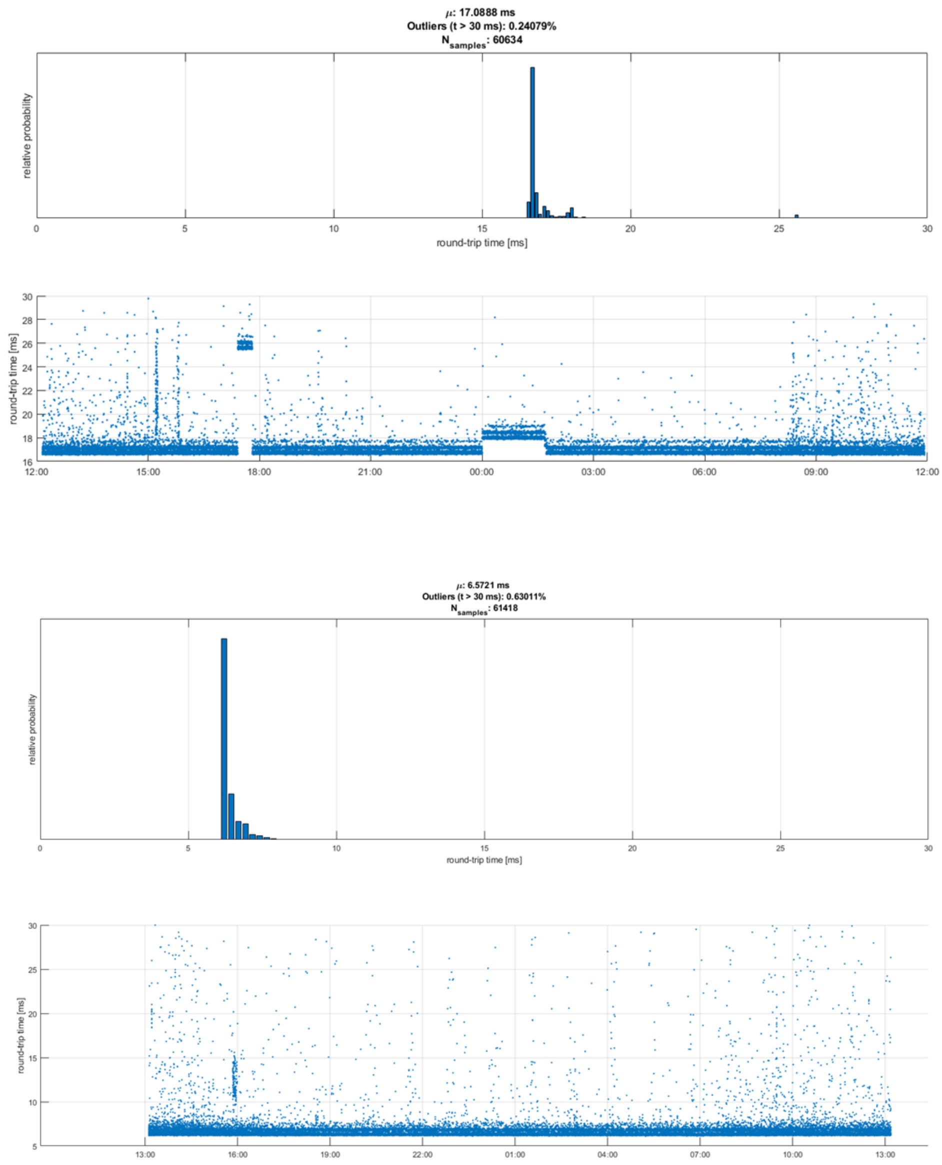

Figure 39: Round trip times for TAU to LUT measurement (top) & TAU to VTT measurement (bottom) - WITHOUT VPN connection.

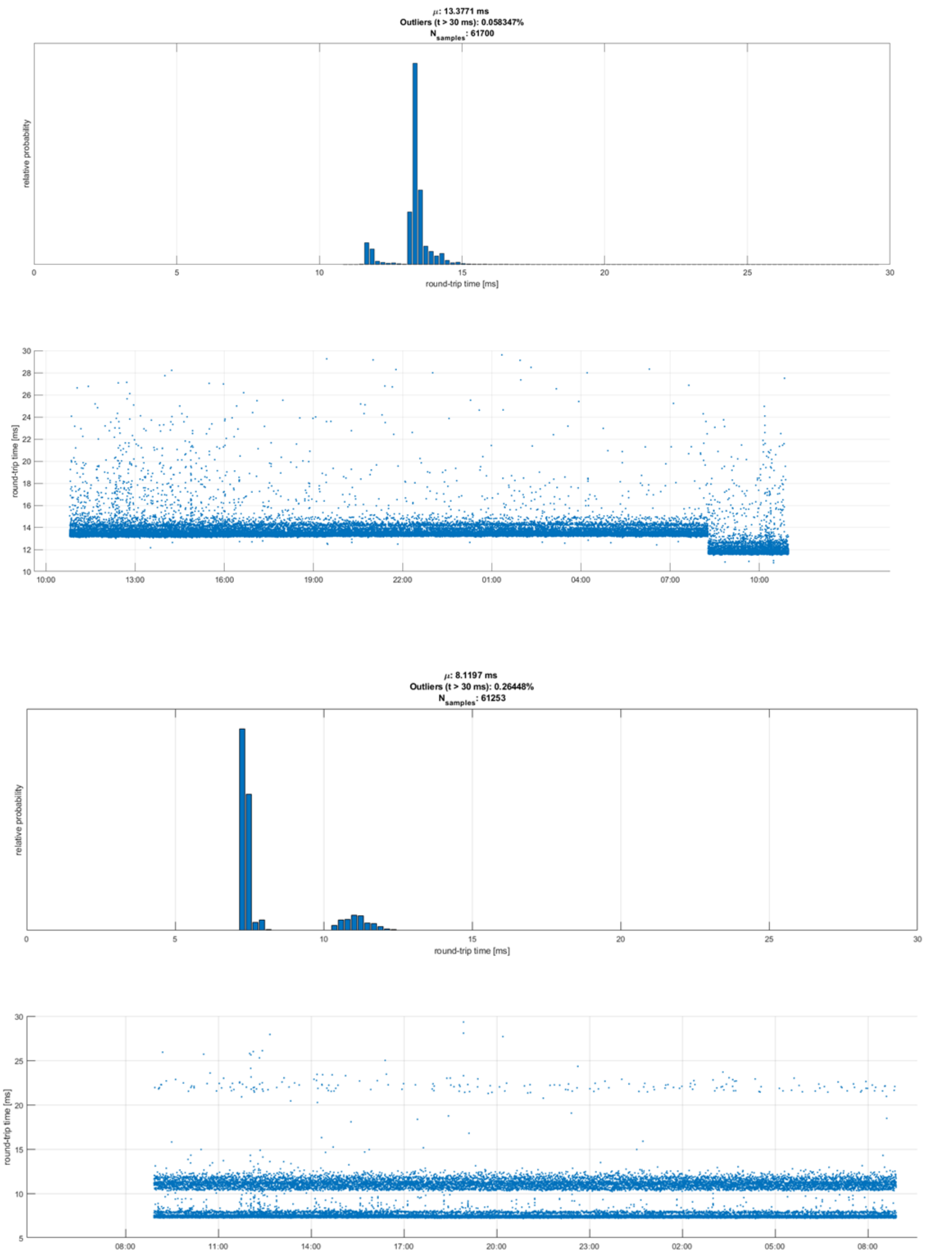

Figure 40: Round trip times for TAU to LUT measurement (top) & TAU to VTT measurement (bottom) - WITH VPN connection.

5 HEILA as an enabler for national smart energy ecosystem

The previous sections describe the technical work conducted in HEILA project. In addition to developing technical solutions for future smart energy functionalities, HEILA has contributed also to defining the national smart energy ecosystem for Finland. Energy business is experiencing several concurrent disruptions related to changes in electricity production, consumption and storage, transport sector and development of ICT. New type of collaboration between different actors is necessary to cope and flourish in the new operational environment. The main contribution of HEILA project towards the national ecosystem is defining and implementing the national testing platform that currently consists of laboratories of LUT, VTT and TAU but is planned to be extended to include also other laboratories and, more importantly, real-life pilot sites. This focal platform enables new type of collaboration between different energy actors and is an important enabler for the smart energy ecosystem. There are also other ongoing activities on smart energy ecosystem topic and HEILA work is closely linked to all of them.

A clear need for defining and building a national-level ecosystem for smart energy has been identified for several reasons. Currently, there are several advanced piloting activities which are, however, a bit scattered at national level. There is a need for integrating the existing pilots and environments better to enable more efficient national innovation environment that is capable of developing, implementing and testing advanced smart energy functionalities, also on system level. At the same the existing infrastructure can be used more efficiently. In addition to the national innovation environment, this will enable Finland to present more significant entities on international level.

Some other development trends also steer more interest towards national ecosystems. Generally, the progress is more towards public–private partnership (PPP)-type instruments where companies, research organizations and public funding organizations are increasingly working together and sharing the funding. On EU level the discussion has been towards innovation hubs which can represent one way for allocating funding in the future. Overall, Finnish initiatives such as Smart Energy program by Business Finland rely strongly on platform and ecosystem structures.

5.1 What is an ecosystem?

There is no established definition for an ecosystem in business world. However, it is widely agreed that a functioning ecosystem should have certain characteristics. For an ecosystem to thrive, it should have a common goal, rules and a strategy to achieve that goal. The goal can be something abstract like enhancing the living conditions or something concrete like creating new export products. An ecosystem is more than just a network of different actors. In a network there is no shared agenda, only individual needs and a network to receive and provide help.

Ideally, an ecosystem is like a living organism where its inhabitants live to achieve a common goal by exploiting and benefiting the ecosystem reciprocally. In order for that to happen the ecosystem needs one facilitator who superintends that the rules are obeyed and the reciprocity is realized. It is not always easy to say what is required from the players to operate in an ecosystem or to what they are eligible/entitled to. In an ecosystem there has to be a shared agenda but it doesn't mean that there couldn't be any individual projects where all the monetary benefits go to individual players. But if a player wants to benefit from the ecosystem, it must also give something to the ecosystem. It could provide, for example, useful data or results of a research.

The idea behind the concept comes from biology and ecosystems in nature. However, it is not exactly the same. In nature, ecosystem provides the living conditions and the rest is a game of life - the fittest will survive. In a business world ecosystem all the inhabitants share a common goal and a will to achieve it.

Ecosystems can be divided into a variety of types (see e.g. [27]) and defined in multiple ways. There are many different ecosystems depending for instance on the general objective and partner profiles. Commonly ecosystems are classified as knowledge ecosystems, innovation ecosystems and business ecosystems. Such classification is not always straightforward as ecosystems typically have some characteristics for these different types. Typically same ecosystem can have more innovation-oriented and more business-oriented activities. Figures 41 and 42 depict the relation of the above mentioned ecosystem types. The national smart energy ecosystem that is aimed for in HEILA and also other currently active initiatives is an innovation ecosystem. The activities in the innovation ecosystem will lead to formation of also business ecosystems. [28]

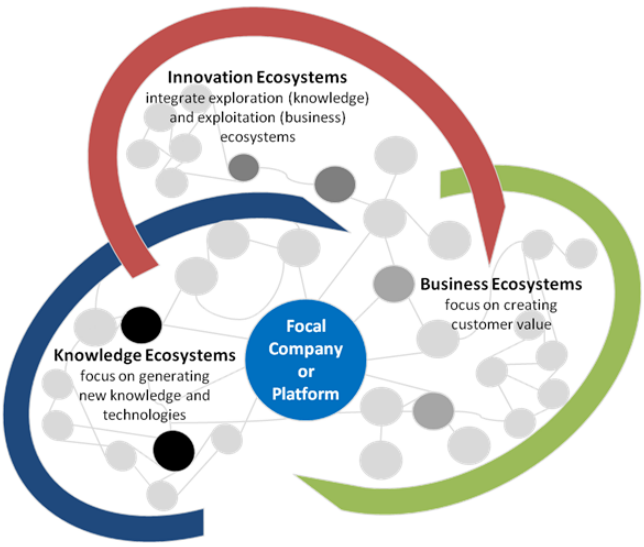

Figure 41: Different types of ecosystems have different goals and actors. All three types of ecosystems build around a focal company or platform and are partly overlapping.

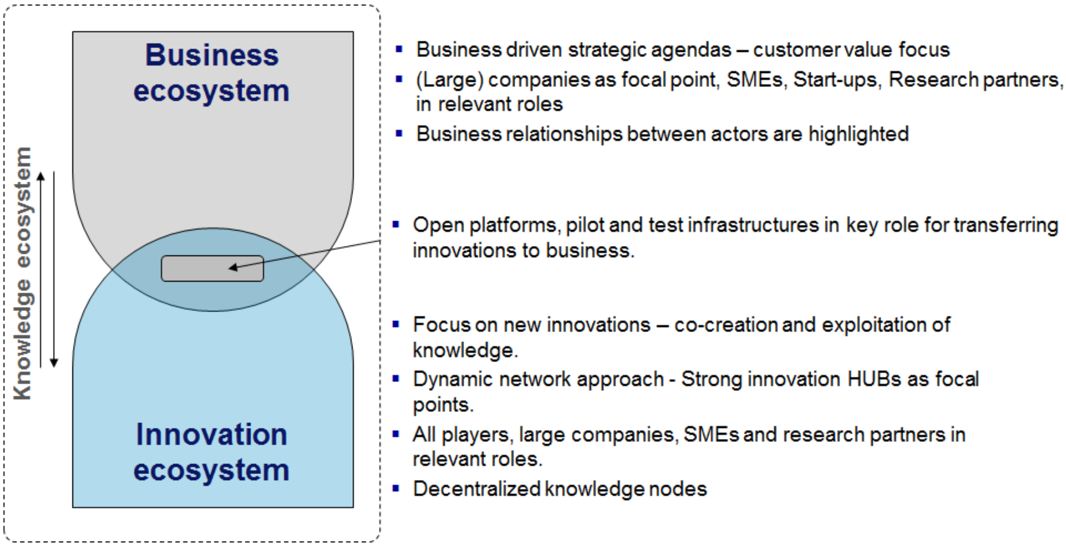

Figure 42: Different types of ecosystems.

Innovation ecosystem has certain typical characteristics. It normally has a common goal which is shared by all participants. Innovation ecosystem is a network of all relevant actors, especially integrating different actors together, for instance big companies and startups or business actors and researchers. Innovation ecosystems are as a principle open and dynamic. They do not have strict management structures nor major formalities. They are not centrally managed, however they are coordinated by a suitable actor. Innovation ecosystems are typically linked internationally with similar or supporting ecosystems. Nationally they seek to have clear impact on national development and discussions for instance around regulation and policies.

Innovation ecosystems are typically based on certain platform or pilot site which they can utilize flexibly. They typically share data and ideas in open manners. Innovation ecosystems also develop ways of working together, including for instance common innovation actions and joint project development. Innovation ecosystems develop new tools for collaboration between the partners for instance within virtual workspaces.

The operation model of an innovation ecosystem is actor-driven and dynamic. Activities can be raised quickly and with efficient preparations whenever there is a common interest within the ecosystem. Activities can be prepared and lead by any partner depending on the situation. For instance research projects are increasingly prepared from need point of view instead of technology development point of view. At the same, the role of common vision becomes essential for identifying the research needs on a high enough level of ambition.

Business ecosystems share many characteristics with innovation ecosystems. However it is clear that they are more business-driven and have more focus on customer values and strategic development agendas. In business ecosystems the actual business relationships between actors are highlighted. More focus is in achieving new business opportunities together.

5.2 Finnish smart energy ecosystem - Smart Energy Finland

Finland, as a member of the European Union, has agreed to decrease its CO2 emissions and to increase the share of renewable power production. The same trend can be widely seen also in other parts of the world. This creates a need to invent new smart energy solutions that are suitable for decentralized and weather dependent power production. In addition to the trend of decarbonization, also digitalization can be seen as a megatrend around the world. Services are shifting online and a new way of combining and exchanging data through digital platforms can be seen as efficient and functional solution. Building such platforms creates a need to understand more than one domain. One needs to understand the users of the service, the markets they operate on and the ICT technology in order to build a functioning and relevant platform.

Finland has certain advantages in the race of creating new smart energy concepts/solutions. We have advanced energy systems with smart grid capabilities, open energy markets with possibilities for new entrants, strong competence in digital technologies and already existing labs, pilot sites and test networks, for example for 5G. The next step is to create larger cross-cutting pilots that would combine the knowledge of multiple domains into comprehensive solutions. First step towards it is bringing together wide range of actors from energy and ICT sectors.

Finnish smart energy ecosystem as a definition means network of all relevant actors, working together for the Finnish agenda within smart energy sector. The ecosystem utilizes a network of pilot and test platforms provided and enabled by HEILA project. As an organization the ecosystem must be flexible and open, meaning efficient management structures and no partnership fees. The ecosystem development work is strongly related to ways of working together in order to enable efficient co-operation and exchange of ideas between the partners. The ecosystem should jointly find new innovations driving the latest development. The ecosystem should also identify new funding schemes for projects developing these innovations. The ecosystem should also be active in national discussions for instance for policy and regulation development.

5.2.1 Workshop results in HEILA project

Workshops have been and will be an important working method when defining the national ecosystem. The ecosystem concept has been discussed in several HEILA steering group meetings and a dedicated workshop for the ecosystem discussion was arranged in March 2018. This subsection represents the results of this workshop. These results have been utilized in HEILA project and the linked parallel activities as an important input for ecosystem definition and forming.

The workshop was divided into two parts. At first, the Finnish smart energy agenda was discussed trying to define common goals for the national smart energy ecosystem. The aim was to define main big objectives, enablers, barriers, gaps and co-operation schemes for the national smart energy ecosystem. As a result of the discussion dozens of ideas were gathered of which the general guidelines will be presented next.

As a common agenda for the whole ecosystem two main concepts were determined. "*Save the world*" refers to global challenge of reducing harmful CO2 emissions and increasing the amount of renewable power production. "*Keep the lights on*" suggests that the focus should also be in maintaining or possibly even improving Finland’s self-sufficiency in energy throughout the year. Other objectives for the ecosystem aim at creating new export products in energy domain and building Finland’s image as a testing platform for advanced energy markets.

During the discussion some key enablers for the Finnish smart energy ecosystem to thrive were recognized. First of all, we already have a complete infrastructure for the smart solutions to take place in energy domain and also strong history in technology and energy cooperation in Finland. Also culture of trial was recognized as a Finnish thing. On the other hand, also some barriers were found challenging the development of strong national ecosystem. Finnish mindset of inadequacy and inability to cash in on innovations were seen as the key challenge. Technology was seen really good, but the ability to commercialize it was not. Also a lack of sufficient amount of global actors in Finland was seen a challenge. Increasing the visibility of energy domain was considered very important.

When further developing the concept of national energy ecosystem, some co-operation schemes were brainstormed. Cross-disciplinary know-how and system knowledge, both pointing towards understanding the big picture, were seen as critically important. As a summary, it was stated that the innovation ecosystem should enable the continuous development of overall competence through co-operation between universities, research organizations and industry.

In the last phase of the ecosystem workshop, actors that should be involved in the ecosystem were listed. Besides the usual energy domain actors, like electricity retailers, DSOs, regulators and TSO, emerging new actors were identified. For example, aggregator, technology and service providers, banks, investors, ministries and building automation manufacturers were added to the list.

5.2.2 HEILA role in Smart Energy Finland - ecosystem

Need for and structure of the national smart energy ecosystem. The energy system is under major disruption which requires new type of collaboration between different actors. Finland can remain as a forerunner in energy sector only if we succeed in forming suitable ecosystems in which actors can combine their capabilities to arrive to competitive solutions in global scale.

New collaboration between companies and also research organizations enables new openings, innovations and business opportunities and growth for Finland. In practice, innovations do not just emerge by themselves but finding the new opportunities requires a lot of discussions and brainstorming together. The national smart energy ecosystem should provide a platform for these kinds of discussions. The ecosystem should benefit all its participants.

The Finnish national smart energy ecosystem forms by combining different piloting areas and previous and ongoing activities in Finland. When the different piloting areas having a different focus are linked, more comprehensive and advanced studies are possible. This will benefit all Finnish stakeholders. A clear consensus on joint national ecosystem has clear benefits on international level networking and builds new Finnish competitiveness both in terms of high-level research and company development activities.

The national smart energy ecosystem consists of individual actors and infrastructures as represented in Figures 43 and 44. The ecosystem structure should be flexible so that the benefits are not lost to excessive bureaucracy but some general rules need to be defined. The ecosystem has different layers of operation: There needs to be a general collaboration layer that provides possibilities for new type of collaboration between ecosystem participants through e.g. joint events, facilitating enhanced knowledge and infrastructure sharing and providing ecosystem guidelines and contract templates. Also joint communication and dissemination activities need to be conducted to guarantee optimal visibility of Finnish know-how internationally and to contribute to export growth. In addition to the general collaboration layer, also a technical layer combining different pilot sites and laboratories is needed. HEILA platform provides technical solutions for this. There needs to be a facilitator taking care of the ecosystem operation.

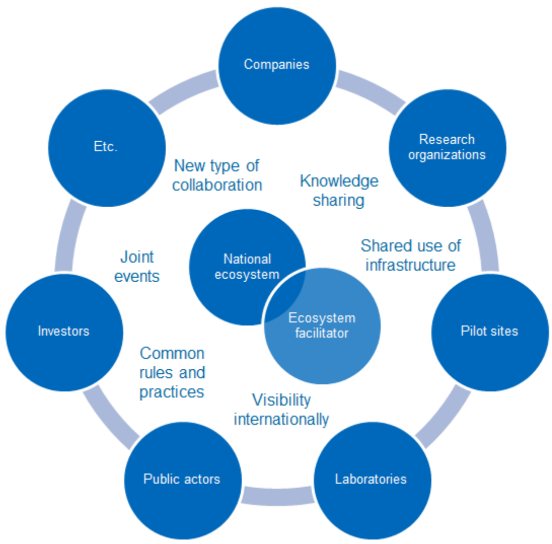

Figure 43: The national smart energy ecosystem links different actors and facilities.

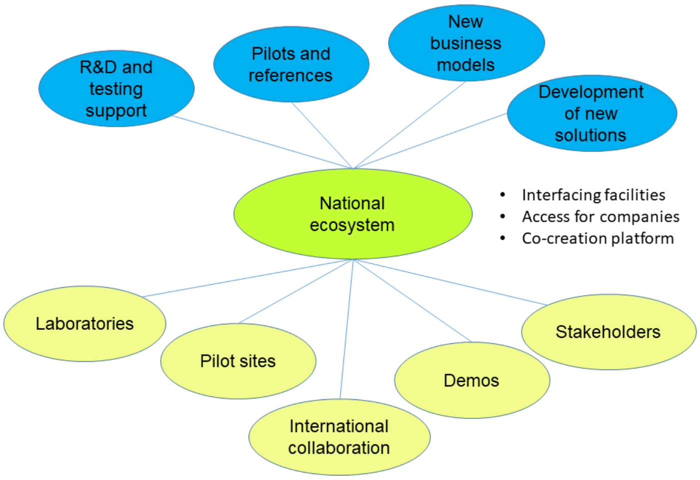

Figure 44: Role of national ecosystem in linking different actors and providing services.

Linking different actors and pilot sites in a nation-wide ecosystem enables developing and testing solutions for all layers depicted in Figure 45. Interoperability is one of the key issues when building the future smart energy system and it is vital to be able to operate on all levels of the system and to initiate collaboration between actors operating on different layers.

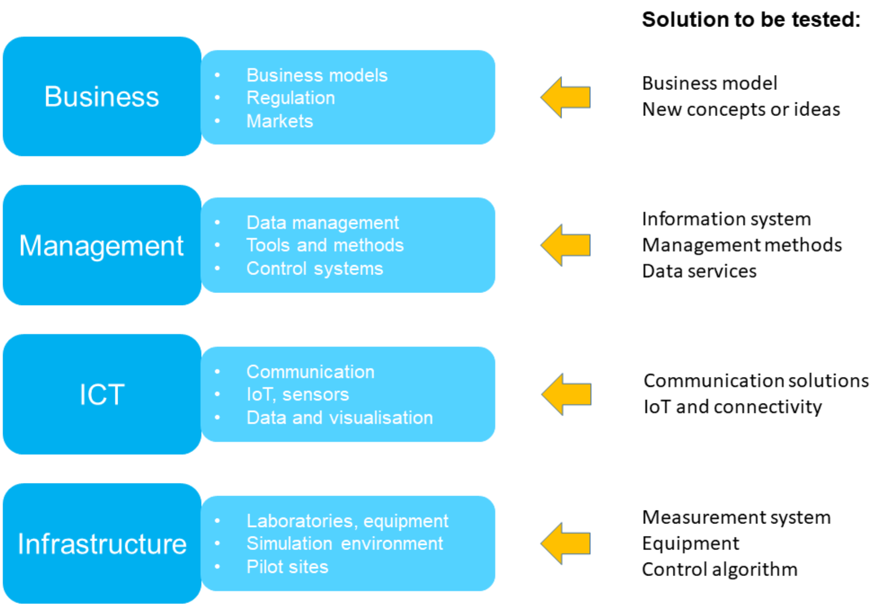

Figure 45: Layer structure and management of interoperability across layers. The ecosystem enables testing of solutions for different layers.

HEILA connects regional pilot platforms and ecosystems There are several regional piloting platforms and ecosystems active in Finland such as Smart Otaniemi, Smart Energy Åland, EnergyVaasa, SENECC, Marjamäki and LUT Green Campus. The national smart energy ecosystem is a collaborative effort of the local platforms and ecosystems as visualized in Figure 46. HEILA platform technical solutions can be used to integrate the different piloting platforms so that the full potential of the platforms can be obtained and also system-level studies conducted. In practice, HEILA platform will enable fast and easy connection of multiple pilots, test sites and labs through one platform where control commands and data exchange can be executed in standardized manner. Figure 47 represents the geographical distribution of some of the pilot sites already existing.

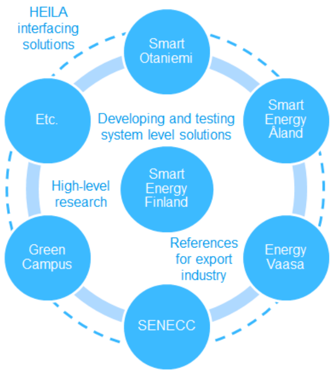

Figure 46: HEILA technical solutions enable integrating local piloting platforms as one nationwide piloting platform.

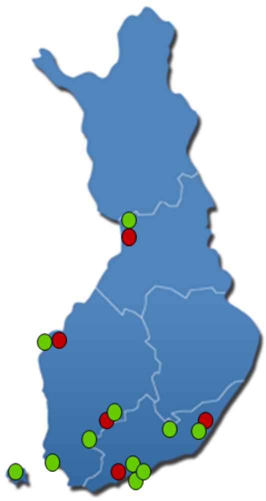

Figure 47: Smart energy pilot sites exist in different parts of Finland.

6 Conclusions

Present trend in power system is decentralization, since most of the renewable energy resources are small and geographically distributed by nature. In addition, microgrids are connecting prosumers and their energy resources locally to other prosumers, enabling local use of energy, prosumers' participation, for instance by peer-to-peer trading, and improving system resilience, as microgrids are able to operate in island-mode in case of grid failure, and they can provide flexibility services for system during grid-connected operation. Eventually, this development arises the need for system integration of the DERs and microgrids, and novel methods for operation of the system of systems. This calls for research and development to innovate technical solutions for interoperable data collection and control interfaces, as well as new market design and regulatory framework for DER integration and prosumer engagement. The objective of HEILA project has been to provide solutions for DER integration based on academic research and laboratory demonstrations.

HEILA platform, that is interoperable information exchange solution for data collection and control, has been developed, and its feasibility has been proved by use case demonstrations. Furthermore, to enable the collection and sharing of the information about the properties of flexibility resources for the use of the market players, metadata register was developed and implemented during the project. Implemented use cases enable integration of the DERs from laboratories and they are based on real-life market rules. Multiple use cases were analyzed during the project, and detailed specifications were provided for three use cases. Eventually, two use cases were demonstrated in project. First one was implemented to show how DERs in microgrids can provide system frequency regulation services by participating in FCR-N hourly markets. Second demonstrated use case was proofing how DERs can provide flexibility services for DSOs. Demonstration of these use cases verify that platform operates as planned, they provide information about its technical characteristics and performance (e.g. transfer times), and reveals further needs for research and development.

Demonstrations prove also that integration of physically distance laboratories may be integrated together at business and functional layers of smart grid architecture model by HEILA platform. This enables implementation of more versatile demonstration and testing during product and service development phase by utilizing resources and functionalities located in different locations in laboratories and pilots representing different market participant. Integration of laboratories and pilots is the key element of the development and testing environment of complex smart grid ecosystem consisting of multi-domain and -partner system of systems. Integration allows development and testing in more realistic and complete system than the testing of individual component of the complete system. In addition to that, implementation of the above illustrated use cases proved out the feasibility of the solution in present markets (FCR-N), as well as in operation that is most probably reality in near future (i.e. DSO flexibility). In addition to technical development of the HEILA platform, the Finnish smart energy ecosystem structure and role of HEILA in that ecosystem have been studied in project.

Business potential of the solution is two-folded; 1) is provides tools needed for management of the domestic power system, and 2) it provides an excellent basis for new services and tools, which can generate new (export) business for technology developers and service providers. However, materialization of this potential cannot be based solely on academic research, but it needs strong participation of the companies, who are likely to exploit the outcomes.

Future research needs are related to developing technical platform towards a plug-and-play product that can be implement to real-life solutions and developing related ecosystem and business model for maintaining the platform. In addition, business models and platform use cases have to be tested against different regulatory frameworks, to ensure the market agnosticism of the solution, and to reveal changes that might be needed in present regulation, market structures and management solutions.

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Appendix I – General Use Cases

Contents

Microgrid monitoring (DSO)

Name: Microgrid data sharing to those who should have access to those (real-time monitoring)

Main actor: DSO

Goal of main actor:

In order to be able to take timely actions to maintain power quality and security of supply, utilize microgrid in island operation, the DSO wants to know:

1. how long a certain microgrid can operation off-grid
2. how long several microgrids can keep a part of the distribution grid in island operation mode; frequency measurement from islanded part (if not otherwise available)
3. net demand of the microgrid (if not otherwise observable)
4. flexibility resources - related information:
    - aggregated SoC / expected SoC (if electric vehicles)
    - DR
    - production curtailment
    - Q capacities
5. obtain a rate (kW, kVAr) at which a microgrid is currently providing flexibility resources to DSO at the PCC/connection point (duplicates DSO Flexibility use-case?)
6. amounts of active power reserves (upwards and downwards) maintained by microgrids (to make sure no congestion is on the way, to minimize own costs for conditional reprofiling products)

Participants:

MO: Operates microgrid and provides/publishes processed data at the level of microgrid to Aggregator(s) and the DSO

Aggregator: an alternative channel for the DSO to obtain technical parameters; publishes price curves, sets amounts of active power reserves maintained by microgrids (probably not relevant)

Preconditions/boundary conditions:

Contracts exist: MOs - Aggregators, DSO-Aggregators (about being an alternative channel)

Microgrid is connected to DSO

DSO knows from which microgrid it wants to obtain monitoring data (DSO knows which Aggregator could provide data if direct monitoring not possible)

Diagram:

Main success scenario:

1. DSO obtains monitoring data from microgrid connected to the DSO's grid

Success guarantee:

DSO obtained monitoring data from microgrid (from the correct one) in time (net demand).

MO(s) log and store the monitoring data for certain period (to resolve any dispute)

Trigger:

DSO tries to obtain/read monitoring data from MO (alternatively from Aggregator)

Exceptions / expansions:

-

Open questions and other requirements: (e.g. regulatory and technical boundaries)

- The information goes directly from MOs to the DSO's the microgrid is connected to, alternatively - via Aggregator.
- Should we include price offers to this use case
- The trading of flexibility between DSO and Aggregator should be open and fair and not include any hidden additional substitute, if the aggregator is the local retailer from the same consolidated corporation

Microgrid monitoring (Aggregator)

Name: Monitoring of Microgrids (Aggregator)

Main actor: Aggregator

Goal of main actor:

1. Monitoring and being aware of flexibility potential on different time scales to make offers on flexibility markets or to upwards actors (e.g. TSO, DSO)

Participants:

- Microgrid operator (MO): publishes the data about flexibility potential of all Microgrid's resources on different time scales to Aggregator in predefined format

Preconditions/boundary conditions:

1. The automation needed for flexibility monitoring, forecasting, data exchange and acquisition is installed on all levels and operates
2. Aggregator is authorized to obtain the flexibility data of MOs
3. ICT infrastructure is secure and reliable
4. Format of data exchange is defined

Diagram:

Main success scenario:

- Aggregator receives the data published by MO(s)
- Aggregator processes the data
- Aggregator updates the data of flexibility potential

Success guarantee:

- The data about potential flexibility of Microgrids are delivered to Aggregator in full volume and standard format sufficient to accurately evaluate available flexibility

Trigger:

- Periodically (e.g. every 1 minute)
- Event based subscription: critical change in flexibility potential or price sensitivity of MO
- Request of Aggregator

Exceptions / expansions:

1a. Aggregator did not receive the data from MO

1a1. Aggregator sends a request to the MO

1a1a. MO returns requested data

1a1b. MO still does not return requested data

1a2b. Aggregator does not consider the corresponding MO for the next predefined period

Open questions and other requirements: (e.g. regulatory and technical boundaries)

Microgrid monitoring (Microgrid operator)

Name:

Main actor: Microgrid operator

Goal of main actor: End results and benefits

Continuous validation of the state of flexibility resources to guarantee purchased flexibility services to different markets

Continuous monitoring of power quality of internal customer (prosumer) connection point

Continuous monitoring of DER states (e.g. SOC/SOH of batteries, output of PV, etc.)

Participants:

Microgrid operator: Operates microgrid

Prosumer: Partner of microgrid, provider of DERs (owned himself or together with other partners), and contract partner for microgrid operator. Prosumer is a passive actor that allows the microgrid operator to monitor its DERs.

DER: Provider of flexibility resources for microgrid (owned together with microgrid partners or single prosumer)

Aggregator: Purchaser of flexibility services

Maintenance service companies: Maintain microgrid IT and automation systems and DERs

Preconditions/boundary conditions:

Microgrid and DERs have a grid connection

DSO is supplying electricity for microgrid (responsible for grid services in microgrid connection point)

Contracts for internal management and ownership of DERs exists

Contracts with Aggregators exists

DERs are observable

Measurement data processing algorithms and systems work without errors.

Diagram:

Main success scenario:

1. Acquiring state of the DERs with reporting (publishing)
2. Data processing: validation, filtering, compressing/aggregation
3. Data storage
4. Data compiling: Extracting information from raw data
5. Real-time monitoring: alarms, events, data flow
6. Off-line monitoring: supervision of (grid component) maintenance needs

Success quarantee:

Valid measurements from the microgrid are received by the microgrid operator.

Trigger:

Microgrid operator: Monetary benefits for microgrid operator for providing flexibility services

Sub-trigger for MO: Monitoring the state for controlling the microgrid is required to ensure the microgrid operation and fulfilling the DSO requirements

Sub-trigger for MO: Microgrid monitoring the state of the DERs, and therefore the microgrid, is required for offering and providing flexibility services

Prosumer: Monetary benefits for prosumer for allowing the microgrid operator to operate prosumer's DERs

DSO: responsibilities of their grid operation

Aggregator: Revenue from trading power products

Maintenance service companies: revenue from maintenance service

Exceptions / expansions:

Microgrid operator gathers DER data by requesting (polling) and not by listening to DER broadcasting.

Faults in monitoring the state, faults in internal DER operation (leading into providing incorrect data), faults in validation algorithm, faults in filtering algorithm, faults in DSO grid, faults in microgrid.

Open questions and other requirements: (e.g. regulatory and technical boundaries)

Permissions for operating DERs with chain ownerships.

FCR (Microgrid operator)

Name: Microgrids as frequency containment reserves (from microgrids' point of view)

Main actor: Microgrid operator (MO)

Goal of main actor: MO wants to efficiently use DERs by providing active power reserves

Participants

Aggregator: wants to pool (a certain minimum amount of) available active power reserves of microgrids and to resell them either on FCR market or to DSOs (for island operation)

DER: wants efficient use of equipment for its faster payback; wants to use equipment for own purpuses too.

Preconditions/boundary conditions:

All required contract between participants exist

All systems work

Diagram:

Main success scenario:

1. MO receives the command from Aggregator to maintain a certain amount of active power reserve (allocation)
2. MO distributes the received allocation to DERs to physically maintain and deliver active power reserves
3. MO monitor DERs to establish actual amounts of maintained and activated reserves
4. MO reports on actual amounts to Aggregator

Success guarantee: Aggregator has timely and complete information on activated and maintained active power reserves from MO

Trigger:

Step 1 of main success scenario

Exceptions / expansions:

1a. DER did not report about its activated or maintained FCR

1a1. communication failure: MO resends a request to the DER

1a2. communication congestion/DER busy: MO makes a conservative assumption about this DER

2a. MO did not publish the data about its activated or maintained FCR

2a1. Aggregator actions similar to 1a1, 1a2

Open questions and other requirements: (e.g. regulatory and technical boundaries)

Ideas about MO reporting to Aggregator:

- time-based report on maintained amount of reserves
- event-based report on activated amounts of reserves

FCR (Aggregator)

Name: Microgrids as frequency containment reserves (from aggregators' point of view)

Main actor: Aggregator

Goal of main actor:

to pool (a certain minimum amount of) available active power reserves of microgrids and to resell them either on FCR market or to DSOs (for island operation)

Participants:

Reserve Market (Platform): wants to provide trading services (possibly for a fee).

Microgrid operator: wants to efficiently use DERs by providing active power reserves.

DSO: wants to avoid network congestion caused by microgirds' participating in frequency regulation (wants to avoid paying for conditional reprofiling products)

Preconditions/boundary conditions:

All the required contracts between participants are in place.

All systems work.

Diagram:

Main success scenario:

1. Aggregator obtains data to establish available active power reserves of microgrids (MOs)
2. Aggregator prepares price bids and submits them to Reserve Markets
3. Aggregator obtains the results of the trading session and optimizes/allocates the to-be-maintained active power reserves to MOs
4. MOs maintain the active power reserves allocated by Aggregators and start sending reports/updates to Aggregators.
5. Aggregator validates the amounts of delivered maintained and activated reserves by each of the MOs (using their reports and updates)
6. Aggregator bills the buyer of active power reserves and send payments to MOs.

Success guarantee:

Aggregators allocated active power reserves to be maintained by MOs and MOs maintained them

The data about ordered and delivered amounts of maintained and activated reserves are logged

Trigger:

Time event: Aggregator prepares to participate on reserve market.

Exceptions / expansions:

Open questions and other requirements: (e.g. regulatory and technical boundaries)

- in case MO can't maintain active power reserves, the Aggregator needs to immediately know about it in order to realize rescheduling

DSO flexibility (Microgrid operator)

Name: Flexibility of distributed energy resources to improve operation of parts of distribution network (from microgrid operators' point of view).

Main actor: Microgrid operator (MO)

Goal of main actor:

To efficiently use DERs by providing flexibility services.

Participants:

Aggregator: wants to gather flexibility services of microgrids and resell them to DSO.

DER owners: want faster payback for equipment, want to use it for own purposes too.

Preconditions/boundary conditions:

All required contracts between the participants are in place

All systems work (data connections, MO's own systems, which collect data from DERs and estimate available amounts of flexibility services, etc.)

MO gets notification from Aggregator to start delivery of a flexibility service.

Main success scenario:

1. MOs provides information on available amounts to Aggregator(s)
2. MOs receive information from Aggregators about (full or partial) acceptance of offers
3. MOs prepare internal running schedules for their DERs
4. MOs report to Aggregators on delivered amounts of services (continuous reporting while delivering)
5. MOs get paid for delivered amounts of flexibility services.

Success guarantee:

Provision of flexibility services does not lead to violation of MO's service obligations within microgrid.

MO receives adequate payment for delivered flexibility services

Trigger:

MO gets notification from Aggregator to start delivery of a flexibility service.

Exceptions / expansions:

-

Open questions and other requirements: (e.g. regulatory and technical boundaries)

-

DSO flexibility (Aggregator)

Name: Flexibility of distributed energy resources to improve operation of parts of distribution network (from aggregators' point of view).

Main actor: Aggregator

Goal of main actor:

To gather flexibility services of microgrids and resell them to DSO.

Participants:

DSO: wants to efficiently manage congestions and power quality by using flexibility services; wants to pay only for delivered service.

Microgrid Operator: wants to efficiently use DERs by providing flexibility services.

Flexibility Market (FM): wants to provide trading services (for a fee if independent from DSO).

Preconditions/boundary conditions:

All necessary contracts between participants are in place.

All systems work (data connections, control systems of DERs, microgrids, etc.)

Aggregator gets a notification that his offered flexibility services accepted.

Main success scenario:

1. Aggregator obtains forecasts and reports from MO(s) containing information about amounts of available flexibility services
2. Aggregator prepares and submits price bids/offers for DSO flexibility services to FM
3. Aggregator receives notification from FM when DSO accepts price offer on FM
4. Aggregator orders MO(s) to activate/schedule the delivery of flexibility service.
5. MO reports to Aggregator about activated resources and the delivery of flexibility service.
6. Aggregator reports to DSO about activated amounts of resources and delivery of flexibility service.
7. Aggregator bills the DSO and pays Microgrid Operators.

Success guarantee:

Delivery of service is possible to validate - continuous validation reporting, data is logged.

Aggregator gets paid after validation of service delivery.

Trigger:

DSO accepts a certain amount of flexibility service offered by Aggregator

Exceptions / expansions:

1. Information in the database is not up-to-date or missing:

    1a. Try obtaining the data by requesting the relevant MO(s).

2. DSO declines the offer

    2a. Stop here

3. Microgrid Operator is not capable of delivering the promised amount of flexibility service.

    3a. Aggregator tries to reallocate delivery to other relevant MOs

Open questions and other requirements:

DSO flexibility (DSO)

Name: Flexibility of distributed energy resources to improve operation of parts of distribution network (from DSOs' point of view).

Main actor: DSO

Goal of main actor:

1. To efficiently manage congestions and power quality by using flexibility services.

Participants:

- Aggregator: wants to gather flexibility services of microgrids and resell them to DSO
- Flexibility market (FM): wants to provide trading services (for a fee if independent from DSO).
- Balance responsible party (BRP): gets informed and compensated by DSO if necessary

Preconditions/boundary conditions:

1. All contracts are in place
2. All systems work (data connections, trading platform, systems of the aggregator and DSO)
3. DSO forecasted a violation of power quality or shortage of transmission capacity

Main success scenario:

- DSO reads price offers about available flexibility of microgrids for desired location/area from FM
- DSO checks technical, economic feasibility of the offer(s), defines plan of possible control actions for the offer(s)
- DSO selects the offer(s) from the FM
- FM sends contract agreement to DSO and when needed DSO issues activation request to Aggregator(s) with needed amount of flexible resources
- DSO gets activation/validation reports from Aggregator(s)
- DSO pays for the requested flexibility service to Aggregator(s)
- DSO informs and compensates BRP(s) if necessary

Success guarantee:

- DSO observes the improvements after validation notification received from Aggregator

Trigger:

- Power quality violation or shortage of transmission capacity

Exceptions / expansions:

1a. Aggregator did not provide the information because of communication channel failure

2a. DSO declines offers that are not technically feasible

3a. DSO declines offers that are not economically feasible

4a. Aggregator(s) could not realize its promises

Open questions and other requirements:

Appendix II – Detailed Use Cases

Contents

Detailed terminology

Actor's Name	*Related functions*	*Actor's Type*	*Actor's Description*
Sensor		Device	A generic sensor such as voltage sensor, current sensor, state sensor, temperature sensor etc. which can be utilized to monitor actual consumer/prosumer's flexibility potential.
Actuator		Device	A device that is responsible for controlling a mechanism or system.
Intelligent Electronic Device (IED)		Device	A microprocessor-based controller.
	Smart Meter (IED.SM)	Device	A measurement device of frequency, power, etc.
	Frequency controller (IED.FC)	Device	A primary frequency controller of DER unit.
Distributed Energy Resource (DER)		Power system equipment	A generating unit, energy storage unit or controllable load at a single location (regardless of ownership), of any nameplate size, on the customer's side of the meter.
Automation System (AS)		IT system	A generic automation system (e.g. HAS, BAS) that involves the control and automation of lighting, heating (such as smart thermostats), ventilation, air conditioning (HVAC), and security, as well as home appliances such as washer/dryers, ovens or refrigerators/freezers.
Customer Energy Management System (CEMS)		IT system	A generic information system (e.g. HEMS, BEMS, etc.) for monitoring and control of customer side's flexible resources (DERs and AS) that optimizes their consumption and generation portfolios to sell this flexibility to upwards stakeholders.
Microgrid Management System (MGMS)		IT system	A system that aggregates and processes the technical information about microgrid for different time periods to optimize scheduling of its resources in order to guarantee quality of supply as well as to allow maximum participation of microgrid resources in flexibility services.
	Data Acquisition (MGMS.DA)	Function	A function that requests the data from external systems and receives the data that were requested as well as published by other actors via broker. An information receiver.
	Data Base Management (MGMS.DBM)	Function	A function that interacts with the database retrieving, storing, and harmonizing the data.
	Data Management (MGMS.DM)	Function	A function that contains the logic of the system operation and handles the data transition within the functions of the system. A data handler.
	Data Processing (MGMS.DP)	Function	A function that checks for correctness, meaningfulness, and security of data that are input to the system.
	Data Transmission (MGMS.DT)	Function	A function that receives requests and transmits the requested data (responses) as well as publishes messages to broker or external systems. An information sender.
	Data Base (MGMS.DB)	Database	A database of MGMS.
	State Estimation (MGMS.SE)	Function	A function that evaluates the real-time state of microgrid based on the data from IEDs (P,Q, U, I) and CEMSs (flex P, Q).

	Reserve Verification (MGMS.RV)	Function	A function that verifies that the DERs were activated in full volume according to the reserved power.
	Flexibility Forecast (MGMS.FF)	Function	A function that forecasts the flexibility of microgrid on different time frames based on the data from IEDs (P, Q, U, I) and CEMSs (flex P, Q), weather forecasts, and historical data.
	Flexibility Control (MGMS.FC)	Function	A function that schedules the microgrid resources in order to realize network management commands from upper level automation systems under operational limits of the microgrid network and individual elements.
	Trading System (MGMS.TS)	Function	A function that divides the revenue between all microgrid DERs that were participating in the flexibility service and those that were utilized for the maintaining of the required power quality levels to gain more flexibility available.
Aggregator Management System (AMS)		IT system	A system that acquires and processes flexibility potential information of microgrids and other controllable resources on different time-scales to propose flexibility services on markets or to upwards actors and provide the management of such services.
	Data Acquisition (AMS.DA)	Function	A function that requests the data from external systems and receives the data that were requested as well as published by other actors via broker. An information receiver.
	Data Base Management (AMS.DBM)	Function	A function that interacts with the database retrieving, storing, and harmonizing the data.
	Data Management (AMS.DM)	Function	A function that contains the logic of the system operation and handles the data transition within the functions of the system. A data handler.
	Data Base (AMS.DB)	Database	A database of AMS.
	Data Processing (AMS.DP)	Function	A function that checks for correctness, meaningfulness, and security of data that are input to the system.
	Data Transmission (AMS.DT)	Function	A function that receives requests and transmits the requested data (responses) as well as publishes messages to broker or external systems. An information sender.
	Trading System (AMS.TS)	Function	A function that performs commercial planning, market negotiations, estimates available flexibility and calculates the bids for the markets.
Distribution Management System (DMS)		IT system	A collection of applications within the system designed to use microgrid flexibility to support of the quality of supply of distribution network.
	Data Acquisition (DMS.DA)	Function	A function that requests the data from external systems and receives the data that were requested as well as published by other actors via broker. An information receiver.
	Data Base Management (DMS.DBM)	Function	A function that interacts with the database retrieving, storing, and harmonizing the data.
	Data Management (DMS.DM)	Function	A function that contains the logic of the system operation and handles the data transition within the functions of the system. A data handler.
	Data Processing (DMS.DP)	Function	A function that checks for correctness, meaningfulness, and security of data that are input to the system.
	Data Transmission (DMS.DT)	Function	A function that receives requests and transmits the requested data (responses) as well as publishes messages to broker or external systems. An information sender.
	Data Base (DMS.DB)	Database	A database of DMS.

	Trading System (DMS.TS)	Function	A function that is in charge of DMS market processes related to the economic analysis of flexibility market offers.
	Island Operation (DMS.IO)	Application	An application that monitors and manages island operation grids via AMS and DMS, validates the implementation of FCR.
	State Forecasting (DMS.SF)	Function	A function that forecasts the state of the network on different time periods as well as identifies the demand for flexibility because of the power quality deterioration.
	State Estimation (DMS.SE)	Function	A function that estimates current state of the distribution network using real-time and pseudo measurements as well as power flow analysis.
	State Optimization (DMS.SO)	Function	A function that predicts the reaction of the network on microgrid power flows and determines the optimal operating levels for microgrid flexibility in order to improve power quality in the network.
	Capacity Validation (DMS.CV)	Function	A function that validates the activation of resources for FCR.
	Activation Verification (DMS.AV)	Function	A function that verifies the proper activation of contracted DER targets
Flexibility Market Platform (FMP)		IT platform	A platform for trading of flexibility services between aggregators and grid operators.
	Market Operations (FMP.MO)		A function that enables interaction between aggregator and other market participants by means of market clearance.
	Location Sorting (FMP.LS)		A function that identifies offers valuable for particular DSO area.
	Data Transmission (DMS.DT)		A function that receives requests and transmits the requested data (responses) as well as publishes messages to broker or external systems. An information sender.
Transmission System Operator Energy Management System (EMS)			A system to monitor, control, and optimize the performance of the transmission system.
	Reserve Allocation (EMS.RA)	Function	A function that determines the necessary amount of reserves for the next day in hourly market.
	Reserve Verification (EMS.RV)	Function	A function that verifies the activation and maintenance of the reserves.
Reserve Market Platform (RMP)		IT platform	A platform for trading of frequency containment reserves on hourly market.
	Market Operations (RMP.MO)	Function	A function that enables interaction between market participants by means of market clearance.
	Merit Order Placement (RMP.MOP)	Function	A function that ensures cost-effective use of offered power by placing them in merit order.
	Data Acquisition (RMP.DA)	Function	A function that requests the data from external systems and receives the data that were requested as well as published by other actors via broker. An information receiver.
	Data Transmission (RMP.DT)	Function	A function that receives requests and transmits the requested data (responses) as well as publishes messages to broker or external systems. An information sender.
Service Provider Platform (SPP)		IT system	A system that provides the forecasts of weather and prices of flexibility/reserve market
	Weather Forecast (SPP.WF)	Function	A function that provides a weather forecast for flexibility resources.

	Price Forecast (SPP.PF)	Function	A function that provides a price forecast for flexibility/reserve market.

Monitoring microgrid DERs (Microgrid operator) detailed

1 Description of the Use Case

Name of Use Case

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	**Domain Expert** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1	24.11.2017	Pyry Lehtimäki	Primary	Core team	Working draft	Draft
Version 0.2 with updated terminology	5.1.2018	Pyry Lehtimäki	Primary	Core team	Working draft	Draft
Version 0.3 (adding technical requirements, harmonizing with implementation use cases)	20.04.2018	Aleksei Mashlakov	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	***Higher Level Use Case***
Monitoring	Microgrid operator monitoring

Maturity of Use Case *– in business operation, realized in demonstration project, realized in R&D, in preparation, visionary*
Under development
Prioritisation
High
Generic, Regional or National Relation
Generic
View *- Technical / Business*
Technical
Further Keywords for Classification

Real-time monitoring, DER monitoring, Microgrid monitoring, Flexibility monitoring

Scope and Objectives of Use Case

Scope of Function
The scope consists continuous monitoring the states of the DERs in the microgrid. Microgrid operator (MO) is the party that executes the monitoring.
Objectives of Function
Acquiring the flexibility state of the microgrid (based on the sates of DERs) in order to be able to provide flexibility services for other parties.

Narrative of Use Case

Short description *– max 3 sentences*
Continuous monitoring the DERs states using subscribing and publishing as well as using requesting when necessary.
Complete description
Continuous monitoring the DER flexibility states using requesting (microgrid operator does polling) and reporting (DERs do publishing). On the Microgrid level, several monitoring devices and systems are needed for data collection and frequency control: • Smart meters and sensors for signals acquisition and processing by DER controller (DER.IED) that is the connection point of microgrid customers/prosumers for microgrid management system (MGMS). The data include measurements with forecasts(e.g. operation plan), when possible to obtain: -generator power output (U, I, P, Q) -potential for change of generator power output (U, I, P, Q, price) -state of charge (SOC) and state of health (SOH) of batteries -potential for charging and discharging of batteries (E, P, I, U, price) -CHP, also cooling, output (U, I, P, Q & heat) -potential for the change of CHP, also cooling, output (U, I, P, Q & heat, price) -state of controllable loads (U, I, P, Q) -potential for change in state of controllable loads (U, I, P, Q, price) There are different scenarios how this interface could be implemented. The Normal Scenario 1 assumes that data about DER state are delivered to MGMS periodically whenever change of the state happened or not (time based). In Alternative scenario 1, DER.IED delivers data to MGMS only in case of change of state (event based). Alternative scenario 2 proposes to deliver data to MGMS only in case of the request of the latter.

Actors: Detailed Terminology

Actor Name *see Detailed Terminology List*	***Actor Type*** *see Detailed Terminology List*	***Actor Description*** *see Detailed Terminology List*	***Further information specific to this Use Case***
DER.IED	Device	Distribution Energy Resource Intelligent Electronic Device	
DER.SM	Device	Distribution Energy Resource Smart Meter	
MGMS	System	Microgrid Management System	

MGMS.DA	Function	Microgrid Management System Data Acquisition	
MGMS.DM	Function	Microgrid Management System Data Management	
MGMS.DP	Function	Microgrid Management System Data Processing	
MGMS.DBM	Function	Microgrid Management System Data Base Management	
MGMS.FF	Function	Microgrid Management System Flexibility Forecast	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	**Reference** – *law, standard, others*

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/ Contract	***Triggering Event***	***Pre-conditions***	***Assumption***	**Post-conditions**
MGMS		Has the technical possibility to monitor the states of the DERs in the microgrid.		
MGMS		The microgrid operator has legal contracts to monitor DERs		
DER		State can be monitored internally and the state can be reported/response sent to microgrid operator.		

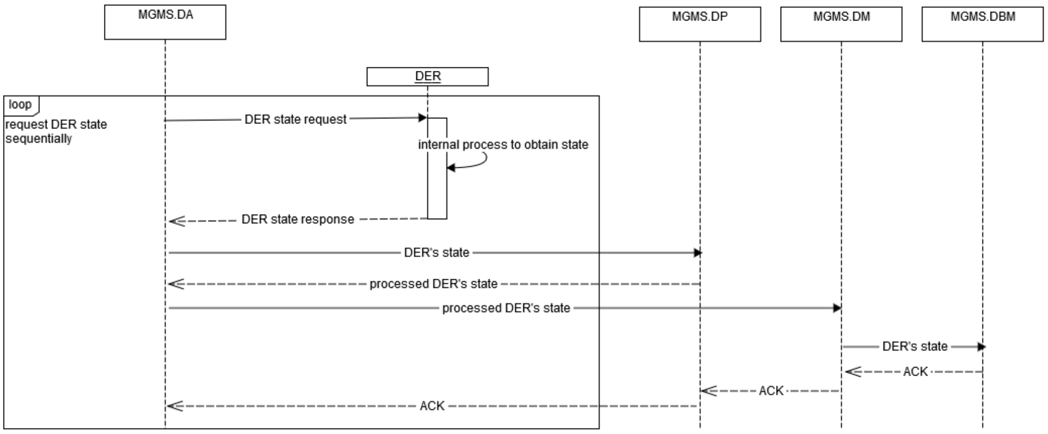
Referenced Standards and / or Standardization Committees (if available)

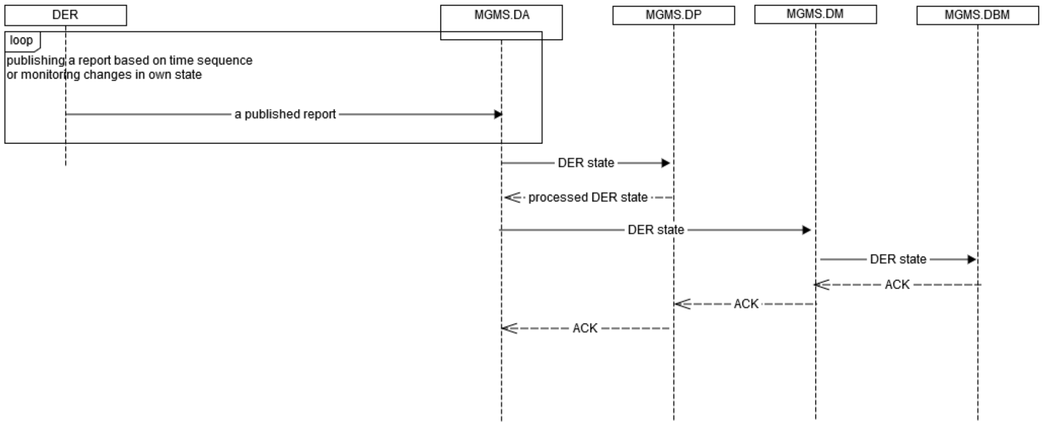
Relevant Standardization Committees	***Standards supporting the Use Case***	***Standard Status***

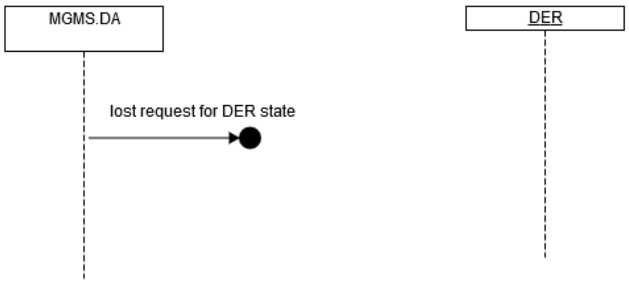
General Remarks

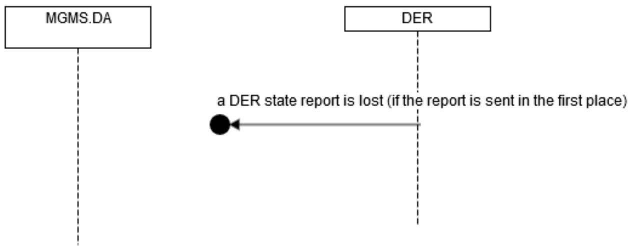
General Remarks

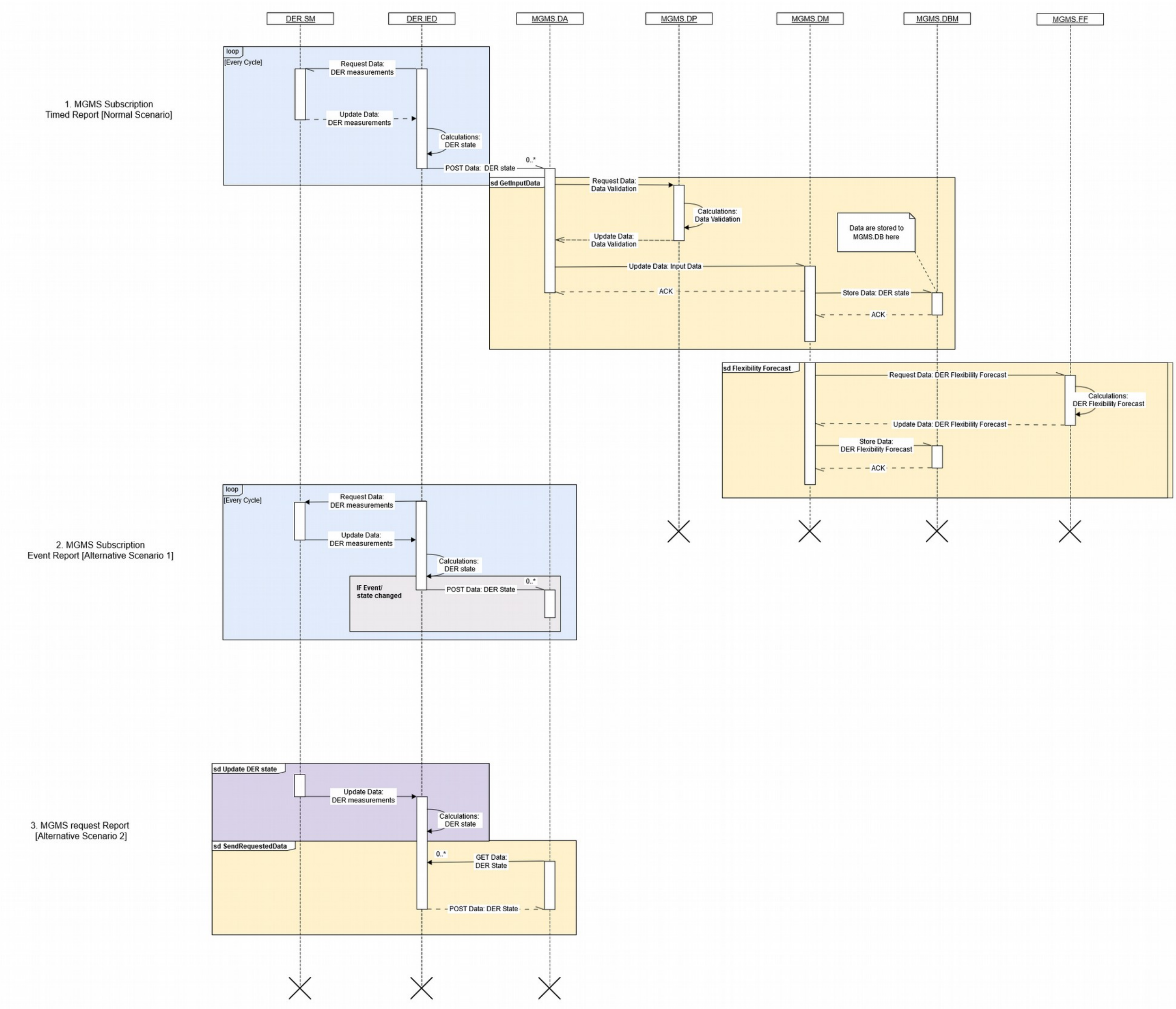
2 Drawing or Diagram of Use Case











3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1: Time based published DER state	DER.IED	Time interval triggers publishing/broadcasting/reporting a DER state (based on a DER parameter i.e. change in DER state).	MGMS.DA has subscribed to event publication (based on pre-defined DER state changes): MGMS has knowledge about all DERs and how to subscribe to their broadcasting/publishing/reporting.	MGMS receives the published DER state report.
Alternative scenario 1: Event based publishing	DER.IED	An event (i.e. an alarm) triggers publishing/broadcasting/reporting a DER state (based on a DER parameter i.e. change in DER state).	MGMS.DA has subscribed to event publication (based on pre-defined DER state changes): MGMS has knowledge about all DERs and how to subscribe to their broadcasting/publishing/reporting.	MGMS receives the published DER state report.
Alternative scenario 2: Requesting DER states sequentially	MGMS.DA	A certain moment (i.e. the beginning) of a request sequence for DER states.	Requests can be done: MGMS has knowledge about all DERs and how to connect/message them.	All DER states are queried that can/need be requested.

Steps – Normal Sequence

Scenario Name :		Primary scenario 1: Time based published DER state				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Periodically Request Data: DER Measurements	DER.IED requests the data from DER.SM	DER.IED	DER.SM	Request signal [der measurements]	TT1 TR4 SA4 A0
2	Data Update: DER Measurements	DER.IED samples data from DER.SM	DER.SM	DER.IED	Report [der measurements]	TT1 TR4 SA4 A0
3	Calculations: DER state	DER.IED calculates current state of the DER	DER.IED	DER.IED	No information exchange	
4	POST Data: DER state	DER.IED publishes a report, that is acquired by MGMS.DA	DER.IED	MGMS.DA	Report [der state]	TT1 TR4 SA4 A0
5	Request Data: Processed Data	MGMS.DA transfers an input data to MGMS.DP	MGMS.DA	MGMS.DP	Request to process data [der state] Report [active power (f)]	TT1 TR4 SA4 A0
6	Calculations: Data validation	MGMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	MGMS.DP	MGMS.DP	No information exchange	
7	Update Data: Processed Data	MGMS.DP returns the processed data to MGMS.DA	MGMS.DP	MGMS.DA	Report [der state]	TT1 TR4 SA4 A0
8	Send Data: DER state	MGMS.DA transfers the processed data to MGMS.DM	MGMS.DA	MGMS.DM	Report [der state]	TT1 TR4 SA4 A0
9	Store Data: DER state	MGMS.DM transmits the report checked by MGMS.DP to MGMS.DBM	MGMS.DM	MGMS.DBM	Request to store data [der state] Report [der state]	TT1 TR4 SA4 A0
10	Request Data: DER Flexibility Forecast	MGMS.DM request DER Flexibility Forecast report	MGMS.DM	MGMS.RV	Request signal [der flexibility forecast] Report [der state]	TT1 TR4 SA4 A0
11	Calculations: DER Flexibility Forecast	MGMS.DP creates DER Flexibility Forecast	MGMS.RV	MGMS.RV	No information exchange	
12	Update Data: DER Flexibility Forecast	MGMS.DP returns the report data to MGMS.DM	MGMS.DP	MGMS.DM	Report [der flexibility forecast]	TT1 TR4 SA4 A0
13	Store Data: DER Flexibility Forecast	MGMS.DM transfers the processed data to MGMS.DBM	MGMS.DM	MGMS.DT	Request signal to store data [der flexibility forecast] Report [der flexibility forecast]	TT1 TR4 SA4 A0

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	Alternative scenario 1: Event based publishing					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
3a1	Event based Data Update: DER state	DER.IED processes and analyses the data, then generates a new report that will be transmitted to the MGMS.DA if DER state has changed	DER.IED	DER.IED	No information exchange	

Scenario Name :	Alternative scenario 2: Requesting DER states sequentially					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
3b1	Request Data: DER state	MGMS.DA requests a data report from DER.IED	MGMS.DA	DER.IED	Request signal [der state]	TT1 TR4 SA4 A0

Scenario Name :	Alternative scenario 1: Requesting DER states fails					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1	Requesting DER states	Requests are sent from Microgrid Management System's function 'Data Aquisition' to a DER that can/need to be queried.	MGMS.DA	None or a DER	None or a request of DER's state	
2	An error occurres between sending a request and receiveng a response	The reason may be anything from internet network operation faults to DER operation faults. The result is the message (the request or the response) is lost.				
3	Microgrid operator does not receive a response	Microgrid operator does not receive a response about DERs' states.		None	None	
4a	Requesting the state of a DER again	Requesting the state of a DER again (might not end in receiving the DER state)				
4b	Predicting a DER state	Using a prediction of the DER state e.g. based on historical behaviour	Historical data/State predictor algorithm	Microgrid operator	DER state prediction	

Scenario Name :	Alternative scenario 2: Publising a DER state fails					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements***

						ID
1	Trigger for broadcast	The state of a DER changes (that should be a trigger publishing) or timing sequence	Internal DER monitoring		Internal DER state	
2	Error occurres that prohibits the DER state report to be received	The reason may be anything from internet network operation faults to DER operation faults.				
3	Microgrid does not receive a report	Microgrid Management System's function 'Data Aquisition' does not receive a report about DER state change			None	
4a	Microgrid knows that a timed report is not received	Microgrid Management System knows that a timed report is not received that an error occurred in reportorting			None	
4b	Microgrid does not know about DER state change	Microgrid Management System does not know about DER state change since Microgrid Management System's function 'Data Aquisition' has not received any reports (that are not based on time sequence)			None	

Monitoring (Aggregator) detailed

1 Description of the Use Case

Name of Use Case

Real-time monitoring of microgrids by Aggregator (RTMM)

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	**Domain Expert** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1: Technical part of the use case	17.11.2017	Author: Aleksei Mashlakov (LUT) Reviewers: Ville Tikka Samuli Honkapuro	Primary	Energy experts, core team	First draft	Draft for comments
Version 0.2: Revised version of 0.1 (adjusted terminology and architecture)	04.01.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Second draft	Draft for review
Version 0.3: Review based on the comments.	26.03.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Final	Final
Version 0.4:			Primary	IT experts		

Basic Information to Use Case

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***

Relation to Higher Level Use Case	
Cluster	***Higher Level Use Case***
Monitor	Flexibility management of Microgrids

Maturity of Use Case
Under development
Prioritization
High

Generic, Regional or National Relation
Generic
***View** - Technical / Business*
Technical
Further Keywords for Classification
Real-time monitoring

Scope and Objectives of Use Case

Scope of Function
The use case consists in monitoring of aggregated data about flexibility potential and reserve verification of microgrids by aggregator. The flexibility data include supply and demand flexibility potential at the point of common coupling (PCC) on different time scales. The verification data contain current operational point of activated microgrid flexibility. Monitoring of detailed technical data within microgrids by aggregator is out of the scope of this use case. The use case reveals only monitoring of lower level data without it further analysis, etc.
Objectives of Function
The flexibility data are needed by aggregator to estimate the available flexible resources that could be offered to the flexibility or reserve markets to maximize financial profits of microgrid flexibility. The verification data are mainly needed by aggregator to verify the delivery of promised service and get financial reward.

Narrative of Use Case

Short description

Monitoring by aggregator is performed by subscription to the updates of aggregated flexibility potential of microgrids for different time periods as well as for reserve verification of microgrids. Aggregator then combines these real-time (reserve verification) data and also analyses forecasted (flexibility potential) data to use them on flexibility and/or reserve markets with maximum financial profit.

“Real-time” in this context could mean something in between 1 millisecond and some minutes (soft real-time).

Complete description

Accurate monitoring and forecasting of microgrid flexibility are the basic processes for aggregator that allow him to achieve sustainable business profit on flexibility/reserve markets by:

- Composing right market strategy
- Decreasing the amount of electricity imbalance
- Verification of the contract promises
- Sharing the income between the participants in a fair way

This use case presents the required interfaces for operation of the RTMM.

Aggregator presented in this interface by aggregator management system (AMS) directly interacts with microgrid management systems (MGMSs) from where it receives new published reports with necessary data, processes them, and utilizes it for verification or flexibility/reserve market bids.

Data considered by the use case are:

- Forecasted values of supply and demand flexibility potential (every cycle ~ 15 min) for market planning
- Soft real-time data used for verification of control commands/frequency regulation

The data publishing of MGMS can happen periodically, based on event/threshold crossed or request. The first two subscription triggers can complement each other if operating together (e.g. if data sharing every minute, the event update can happen during this minute).

Actors: Detailed Terminology

Actor Name	*Actor Type*	*Actor Description*	*Further information specific to this Use Case*
AMS	System	Aggregator Management System	
AMS.DM	Function	Aggregator Management System Data Management	
AMS.DBM	Function	Aggregator Management System Data Base Management	
AMS.DA	Function	Aggregator Management System Data Acquisition	
AMS.DP	Function	Aggregator Management System Data Processing	
DMS	System	Distribution Management System	
DMS.DA	Function	Distribution Management System Data Acquisition	
MGMS	System	Microgrid Management System	
MGMS.DM	Function	Microgrid Management System Data Management	
MGMS.DBM	Function	Microgrid Management System Data Base Management	
MGMS.DT	Function	Microgrid Management System Data Transmission	
MGMS.FO	Function	Microgrid Management System Flexibility Optimization	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	*Impact of Issue on Use Case*	**Reference** *– law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs is required as input of the AMS. Pre-condition: MGMS has all the rights/contracts to **share** internal data to AMS.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
AMS		The system is up and running.		
MGMS		The system is up and running.		

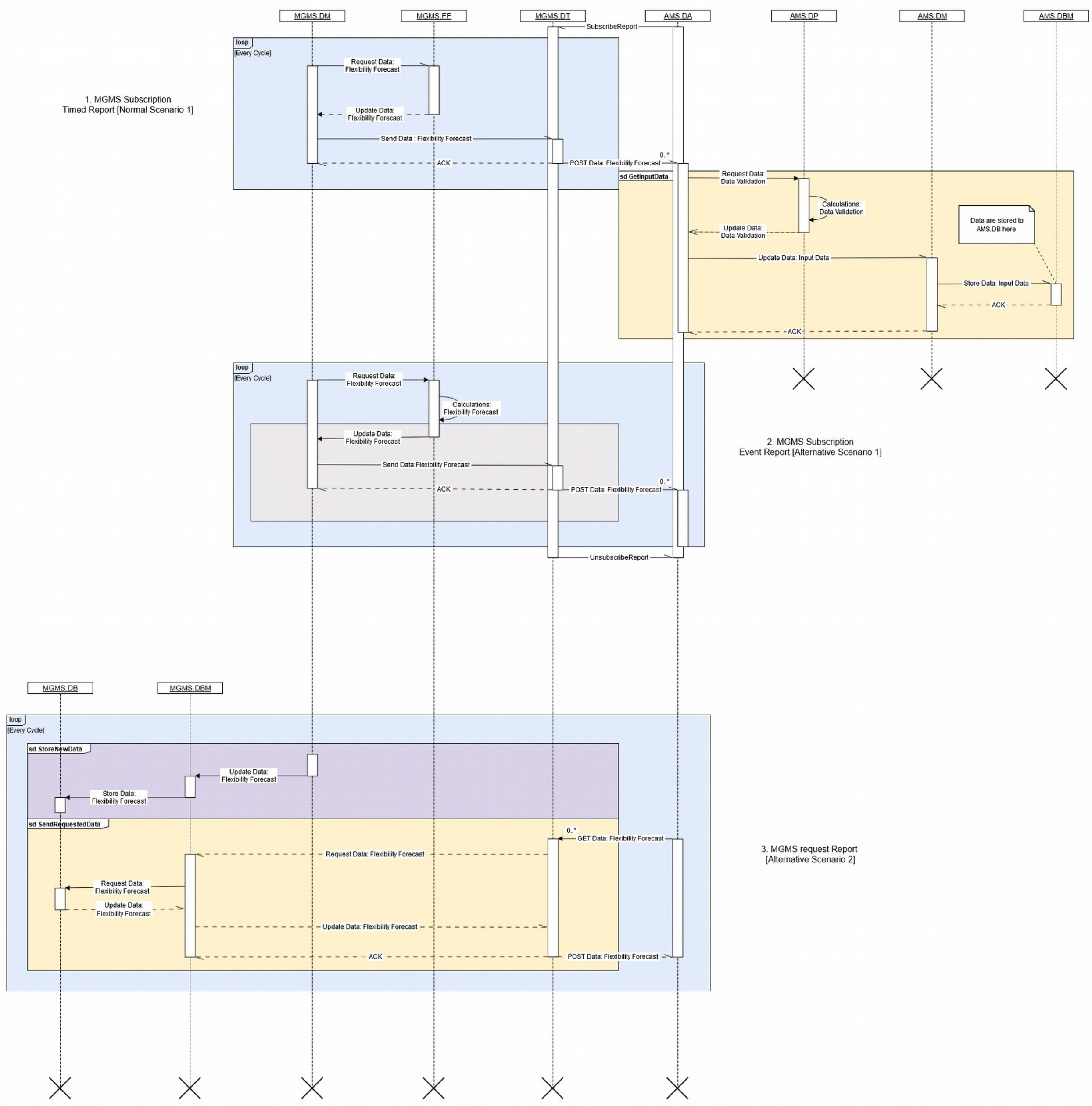
Referenced Standards and / or Standardization Committees (if available)

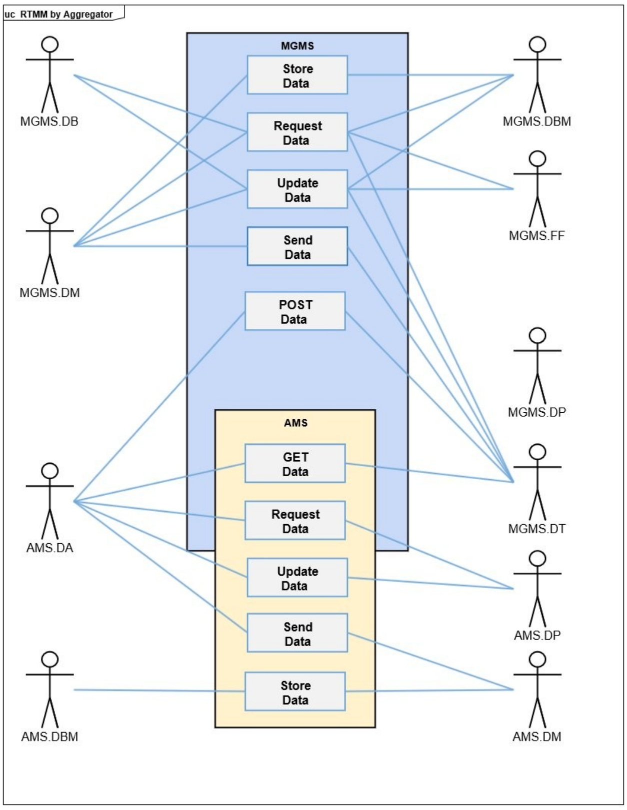
Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

General Remarks

General Remarks

2 Drawing or Diagram of Use Case





3 Step by Step Analysis of Use Case

Scenatio No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1. NS1: Time based report from MGMS	MGMS	Periodically data report is generated by MGMS and delivered to AMS.	AMS has subscribed for flexibility updates of MGMS.	The data about potential flexibility of microgrids is stored in AMS.DB.
2. AS1: Event based report from MGMS	MGMS	Event based data report is generated by MGMS and delivered to AMS.	MGMS settings includes monitoring of threshold values and event report.	The data about potential flexibility of microgrids is stored in AMS.DB.
3. AS2: Request from AMS	AMS	AMS requests a data report from MGMS.	Request - response communication is settled between MGMS and AMS.	The data about potential flexibility of microgrids is stored in AMS.DB.
4. AS3: Report from MGMSs failed	AMS	No data were acquired after a timeout or request.	Request was sent to MGMS or timeout is settled in case of subscription.	The data about potential flexibility of microgrids is *not* stored in AMS.DB.

Steps – Normal Sequence

Scenario Name :		*1.NS1: Time based report from MGMSs*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario *Steps specified for flexibility forecast are also valid for verification notification						
1	Request Data:	MGMS.DM periodically requests the	MGMS.DM	MGMS.FF	Request signal	TT1 TR4 SA2 A0

	Flexibility Forecast	report from MGMS.FF			[flexibility forecast] Report [microgrid measurements] Report [weather forecast]	
2	Calculations: Flexibility Forecast	MGMS.FF calculates flexibility forecast	MGMS.FF	MGMS.FF	No information exchanged	
3	Update Data: Flexibility Forecast	MGMS.FF transmits an updated report to MGMS.DM	MGMS.FF	MGMS.DM	Report [flexibility forecast]	TT1 TR4 SA2 A0
4	Send Data: Flexibility Forecast	MGMS.DM transfers a report to MGMS.DT	MGMS.DM	MGMS.DT	Send signal [flexibility forecast] Report [flexibility forecast]	TT1 TR4 SA2 A0
5	POST Data: Flexibility Forecast	MGMS.DT POST a report to AMS.DA	MGMS.DT	AMS.DA	Report [flexibility forecast]	TT1 TR4 SA4 A0
6	Request Data: Data Validation	AMS.DA transfers an input data to AMS.DP	AMS.DA	AMS.DP	Send signal [data validation] Report [input data]	TT1 TR4 SA2 A0
7	Calculations: Data validation	AMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	AMS.DP	AMS.DP	No information exchange	
8	Update Data: Data Validation	AMS.DP returns the processed data to AMS.DA	AMS.DP	AMS.DA	Report [data validation] Alarm signal [data validation]	TT1 TR4 SA2 A0
9	Store Data: Input Data	AMS.DA transfers the processed data to AMS.DBM to store them	AMS.DA	AMS.DBM	Store signal [Input data] Report [data validation]	TT1 TR4 SA2 A0
10	Data Storage: Input Data	AMS.DBM stores the report checked by AMS.DP	AMS.DBM	ASM.DB	Report [data validation]	TT1 TR4 SA2 A0

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	*2. AS1: Event based report from MGMSs*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
4a1	Send Data: Flexibility Forecast	MGMS.DM transfers a report to MGMS.DT if threshold is crossed	MGMS.DM	MGMS.DT	Send signal [flexibility forecast] Report [flexibility forecast]	TT1 TR4 SA2 A0

Scenario Name :	*3. AS2: Request from AMS*

Step No.	*Event*	*Description of Process/Activity*	*Information Producer*	*Information Receiver*	*Information Exchanged*	*Technical Requirements ID*
1-4a1	GET Data: Flexibility Forecast	AMS.DA requests a data report from MGMS.DT	AMS.DA	MGMS.DT	Request signal [flexibility forecast]	TT1 TR4 SA4 A0
1-4a2	Request Data: Flexibility Forecast	MGMS.DT requests Flexibility Forecast from MGMS.DBM	MGMS.DT	MGMS.DBM	Request signal [flexibility forecast]	TT1 TR4 SA2 A0
1-4a3	Request Data: Flexibility Forecast	MGMS.DBM retrieves the data from MGMS.DB	MGMS.DBM	MGMS.DB	Request signal [flexibility forecast]	TT1 TR4 SA2 A0
1-4a4	Update Data: Flexibility Forecast	MGMS.DM retrieves the data from MGMS.DB	MGMS.DB	MGMS.DBM	Report [flexibility forecast]	TT1 TR4 SA2 A0

Scenario Name :	*4. AS3: Report from MGMSs failed*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
5a1	POST Data: Flexibility Forecast	MGMS.DT could not transmit a report to AMS.DA because an error occurred between end points	MGMS.DT	AMS.DA	NONE	
5a2	POST Data: Flexibility Forecast	AMS.DA notifies AMS.DT that some microgrid has not respond	AMS.DA	AMS.DT	Notification signal [flexibility forecast]	
5a3	POST Data: Flexibility Forecast	AMS.DT sends request to AMS.DA	AMS.DT	MGMS.DA	Request signal [flexibility forecast]	

Monitoring (DSO) detailed

1 Description of the Use Case

Name of Use Case

Microgrid monitoring by DSO

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	**Domain Expert** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1	17.11.2017	Author: Matti Aro (VTT)	Primary	Power grid operations	First draft	Draft for review
Version 0.2 Revised version of 0.1 (adjusted terminology and architecture)	5.1.2018	Matti Aro (VTT)	Primary	Core team	Second draft	Draft for review
Version 0.3 Changes based on reviews	18.1.2018	Matti Aro (VTT)	Primary	Core team	Third draft	Draft for review
Version 0.4 Changes to architecture and sequence diagram	26.4.2018	Matti Aro (VTT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	***Higher Level Use Case***
Data monitoring	Management of flexible resources

Maturity of Use Case *– in business operation, realized in demonstration project, realised in R&D, in preparation, visionary*
Under development
Prioritisation
High
Generic, Regional or National Relation
Generic
View *- Technical / Business*
Technical
Further Keywords for Classification
Real-time data sharing, monitoring

Scope and Objectives of Use Case

Scope of Function
Monitoring is part of a more generic scheme - management of Distributed Energy Resources. Monitoring enables DSO to optimize

and plan the use of its own network.
Objectives of Function
Objective of monitoring (real-time data sharing) is to allow DSO to monitor the state and operation of microgrid, for example, in order to prepare for congestion management.

Narrative of Use Case

Short description *– max 3 sentences*
This Use Case demonstrates data exchange between Microgrid Operator (MO) and Distribution System Operator (DSO) via third party - Aggregator.
Complete description
The main functionality of monitoring is to help in power grid management. Monitoring in this Use Case is meant to reach the following goal: • Provide verification of ordered regulations in the monitored area (verification of adjustments) DSO monitors microgrid through Aggregator: • Aggregator monitors microgrid and passes the information to DSO. DSO is presented in this interface by Distribution Management System (DMS) and directly interacts with Aggregator Management System (AMS) from where it receives new published reports with necessary data to verify the operation of contracted Distributed Energy Resources (DERs) Data considered by the use case are: • Time-series reports used for verification of control commands The data publishing by AMS can happen periodically, based on event/threshold crossed or by request.

Actors: Detailed Terminology

Actor Name *see Detailed Terminology List*	***Actor Type*** *see Detailed Terminology List*	***Actor Description*** *see Detailed Terminology List*	***Further information specific to this Use Case***
DMS	IT system	Distribution Management System	
DMS.DA	Function	Distribution Management System Data Acquisition	
DMS.DM	Function	Distribution Management System Data Management	
DMS.AV	Function	Distribution Management System Activation Verification	
DMS.DB	Function	Distribution Management System Database	
DMS.DBM	Function	Distribution Management System Database Management	
AMS	IT system	Aggregator Management System	
AMS.DT	Function	Aggregator Management System Data Transmission	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	***Reference*** *– law, standard, others*
Customer-owned DER information	Data from customer-owned DERs is required as an input for the EMS	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
AMS		The system is up and running		
DMS		The system is up and running		

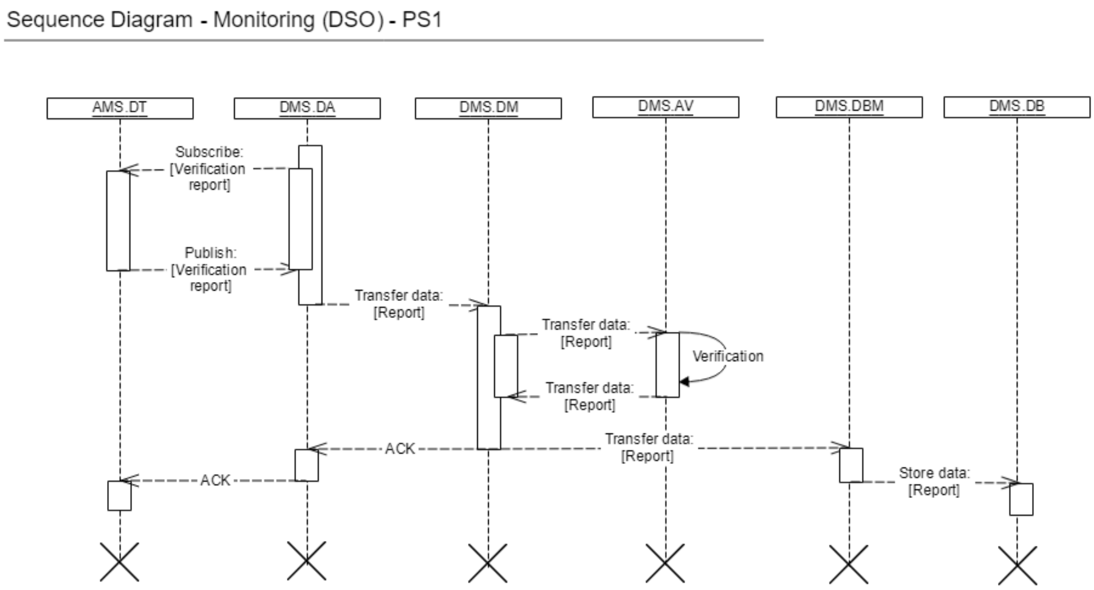
Referenced Standards and / or Standardization Committees (if available)

Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

General Remarks

General Remarks

2 Drawing or Diagram of Use Case



3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1	DMS	Contract has been created between MO and DSO about using flexible resources	DSO has subscribed for monitoring the microgrid reports via Aggregator	Data from microgrid is analyzed and stored in DSO's database

Steps – Normal Sequence

Note: Each row in the following table is equal to each arrow depicted in sequence diagram.

Scenario Name :	*PS1: Adjustment verification*					
Step No.	*Event*	*Description of Process/Activity*	*Information Producer*	*Information Receiver*	*Information Exchanged*	*Technical Require-ments ID*
1	Regulation is supposed to be happened	AMS.DT publishes data about executed adjustments and	AMS.DT	DMS.DA	Report (Executed regulation)	TT1, TR4, SA4, A0

		DMS.DA acquires it				
2	Data is acquired by DMS.DA	DMS.DA transfers the received report to DMS.DM	DMS.DA	DMS.DM	Report (Executed regulation)	TT1, TR4, SA2, A0
3	Data is delivered to DMS.DM	DMS.DM transfers the received report to DMS.AV	DMS.DM	DMS.AV	Report (Executed regulation)	TT1, TR4, SA2, A0
4	Data is delivered to DMS.AV	Report is verified by DMS.AV and transferred back to DMS.DM	DMS.AV	DMS.DM	Verified report	TT1, TR4, SA2, A0
5a	Verified report is transferred to DMS.DM	Report is transferred to Database Management	DMS.DM	DMS.DBM	Verified report	TT1, TR4, SA2, A0
5b	Acknowledgement is transferred to DMS.DM	Acknowledgement report of approved DER operation is transferred to DMS.DA	DMS.DM	DMS.DA	Acknowledgement report	TT1, TR4, SA2, A0
6a	Verified report is ready to be transferred to database	Report is stored into database	DMS.DBM	DMS.DB	Verified report	TT1, TR4, SA2, A0
6b	Acknowledgement is transferred to DMS.DA	Acknowledgement report of approved DER operation is sent to AMS.DT	DMS.DA	AMS.DT	Acknowledgement report	TT1, TR4, SA4, A0

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	*AS1: Normal sequence*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***

FCR (Microgrid operator) detailed

1 Description of the Use Case

Name of Use Case

Frequency containment reserve (FCR) by microgrid operator (MO)

Version Management

Changes / Version	*Date*	*Name Author(s) or Committee*	**Domain Expert** Primary, additional	*Area of Expertise / Domain / Role*	*Title*	*Approval Status* draft, for comments, for voting, final
Version 0.1: Technical part of the use case	17.11.2017	Author: Aleksei Mashlakov (LUT) Reviewers: Ville Tikka Samuli Honkapuro	Primary	Energy experts, core team	First draft	Draft for comments
Version 0.2: (adjusted terminology)	04.01.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Second draft	Draft for review
Version 0.3: (Harmonizing detailed use cases with Implementation use case)	11.04.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	*Link*	*Conditions (limitations) of Use*

Relation to Higher Level Use Case	
Cluster	*Higher Level Use Case*
Monitoring	Flexibility management of Microgrids

Maturity of Use Case
Under development
Prioritization
High
Generic, Regional or National Relation
Generic
View *- Technical / Business*

Technical
Further Keywords for Classification
FCR, flexibility management, microgrid management

Scope and Objectives of Use Case

Scope of Function
The use case consists in process description of maintenance, activation, and verification of Frequency Containment Reserve (FCR) by microgrid operator (MO).
Objectives of Function
This use case allows MO to obtain compensation for the FCR flexibility services.

Narrative of Use Case

***Short description** – max 3 sentences*

Initially, MO carries out a flexibility forecast and then transmits the data to Aggregator that tries to sell this flexibility on the hourly FCR market. Then, if microgrid flexibility was reserved, MO provides frequency control, collects the data about activated and maintained FCR to send them to Aggregator for verification.

Complete description

Verification of the activation and maintenance of the reserve capacity is a part of the Aggregator's responsibilities in front of the other market parties. This functionality is based on the MO reports that are needed to:

- check declared promises of these resources
- fairly divide revenue between resources of microgrids participating in FCR
- provide proof of work for upwards market actors

On the Microgrid level, several monitoring devices and systems are needed for data collection and frequency control:

- Smart meters and sensors for signals acquisition and processing by frequency controller (IED.FC) that is the connection point of microgrid customers/prosumers for microgrid management system (MGMS).

Aggregator that is presented in this interface as a aggregator management system (AMS) directly interacts only with MGMSs from where it receives new published reports with necessary data.

Data acquisition considered by the use case are:

- Time-stamped or frequency synchronized aggregated flexibility capacity (kW) activated or maintained for FCR.

There are different scenarios how this interface could be implemented. The Normal Scenario 1 assumes that data about FCR maintenance are delivered to MGMS and consequently to AMS periodically whenever FCR activation took place or not (time based). In Alternative scenario 1, IED.FC delivers data to MGMS as well as MGMSs to AMS only in case of FCR activation (event based). Alternative scenario 2 proposes to deliver data to MGMS and AMS only in case of the request.

The use case can be divided in the following parts:

1. Flexibility Forecast: MGMS defines the available flexibility for the next 36 hours based on the weather forecast of Service Provider, historical data of microgrid loads, etc.*
*The part of the UC devoted to the initial flexibility monitoring is omitted since it is described in monitoring UC.
2. Reserve Notification: AMS notifies MGMS about the amount of flexibility needed to be maintained for FCR, MGMS reserves necessary volume of the resources giving corresponding control commands to IED.FC.
3. Frequency control: Scheduled resources of microgrid provide frequency support
4. Reserve Verification: Scheduled resources of microgrid share the data about current actual volume of the reserve maintained and activated to MGMS, MGMS analyzes the obtained data and verifies that control commands were made in accordance with scheduled reserve notification, then it sends these data to AMS.

Actors: Detailed Terminology

Actor Name	*Actor Type*	*Actor Description*	*Further information specific to this Use Case*
IED.FC	Device	Intelligent Electronic Device Frequency Controller	
IED.SM	Device	Intelligent Electronic Device Smart Meter	
MGMS	System	Microgrid Management System	
MGMS.DA	Function	Microgrid Management System Data Acquisition	
MGMS.DP	Function	Microgrid Management System Data Processing	
MGMS.DT	Function	Microgrid Management System Data Transmission	
MGMS.DM	Function	Microgrid Management System Data Management	
MGMS.DBM	Function	Microgrid Management System Data Base Management	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	*Impact of Issue on Use Case*	***Reference** – law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs is required as input of the MGMS.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
MGMS		The system is up and running.		
IED.FC		The device is up and running.		
IED.SM		The device is up and running.		

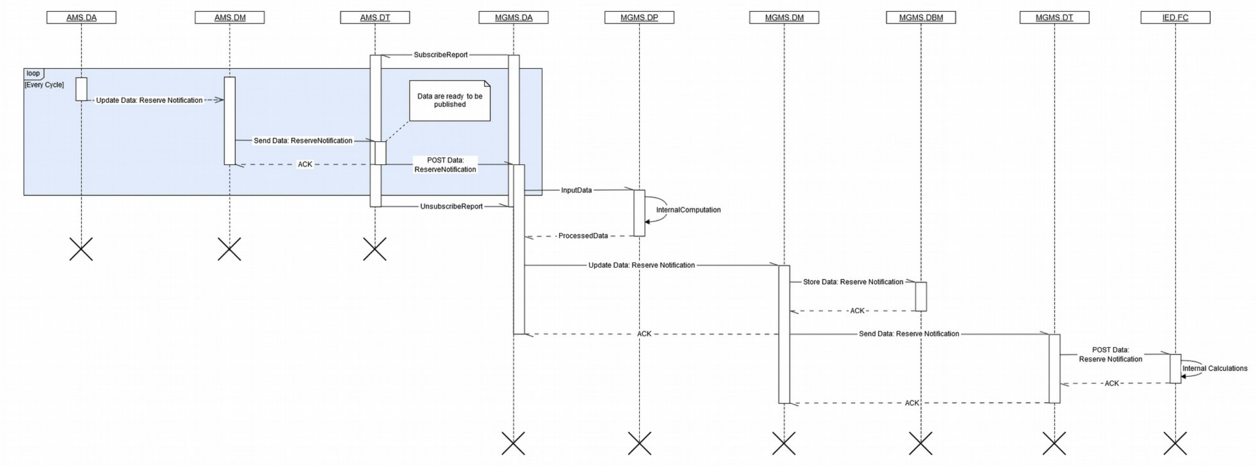
Referenced Standards and / or Standardization Committees (if available)

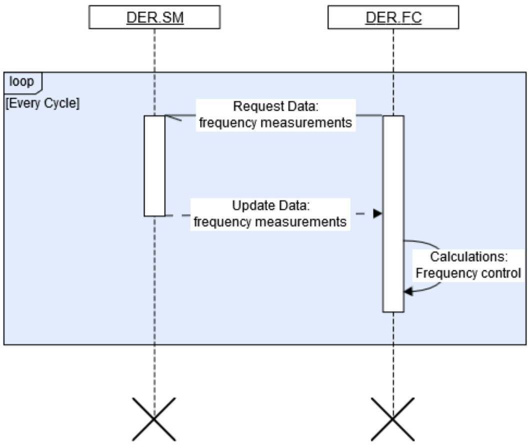
Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

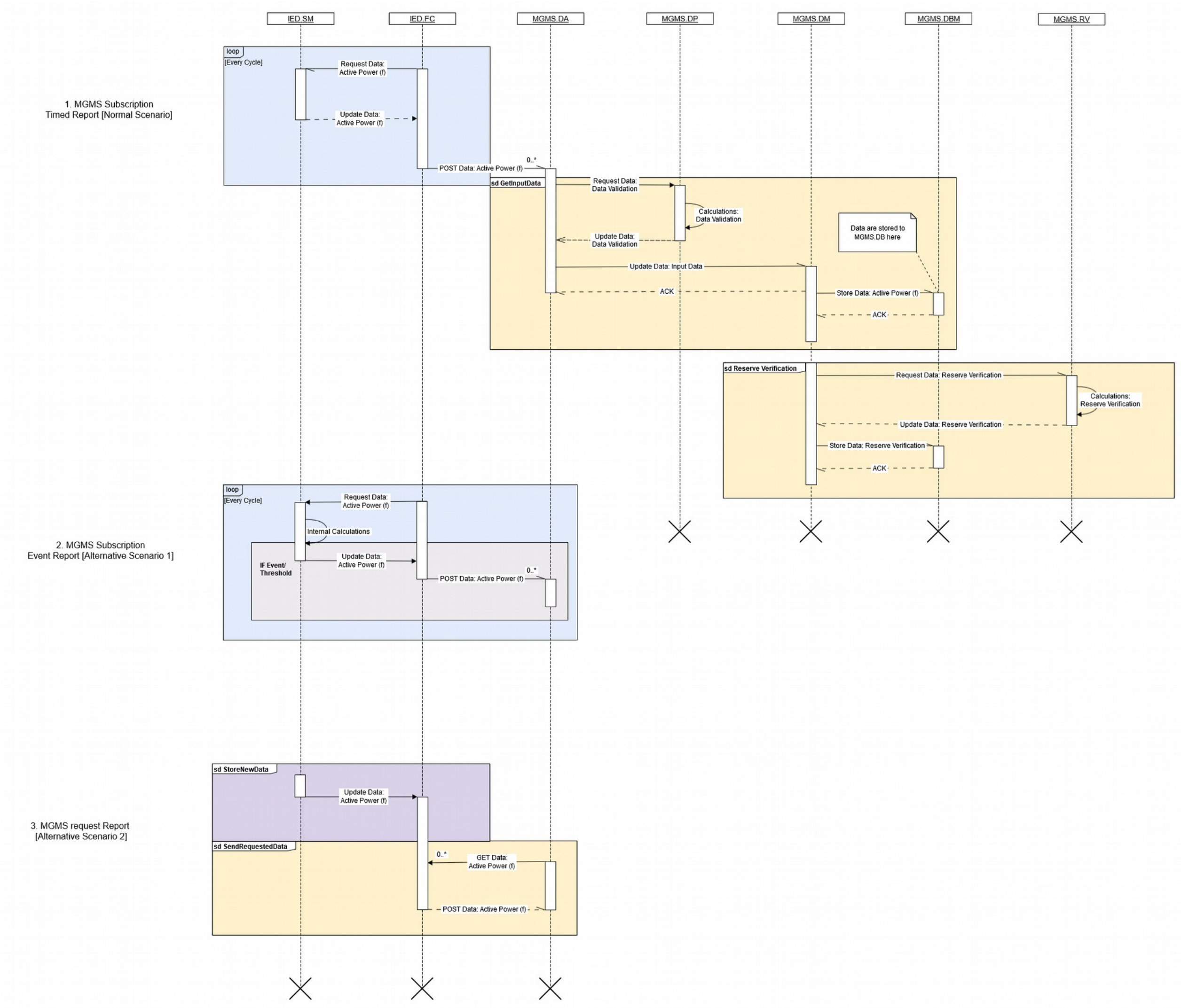
General Remarks

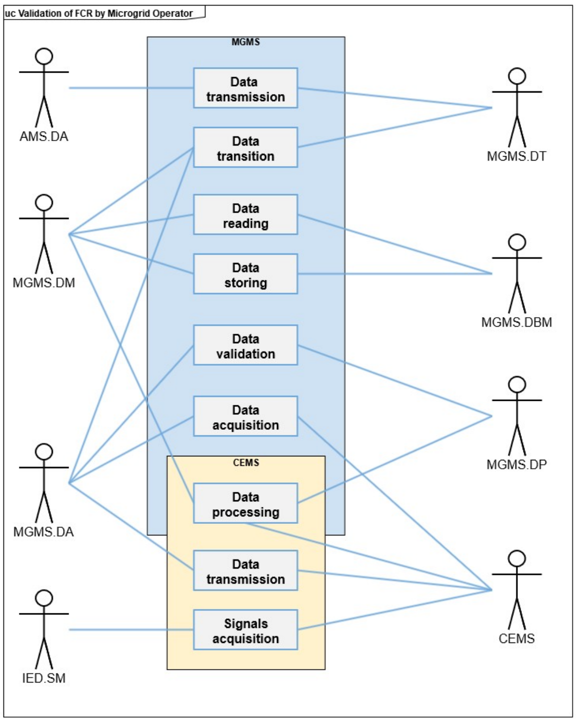
General Remarks

2 Drawing or Diagram of Use Case






IED.SM
IED.FC
MGMS.DA
MGMS.DP
MGMS.DM
MGMS.DBM
MGMS.RV
loop
[Every Cycle]
1. MGMS Subscription
Timed Report [Normal Scenario]
Request Data:
Active Power (f)
Update Data:
Active Power (f)
POST Data: Active Power (f)
0..*
sd GetInputData
Request Data:
Data Validation
Calculations:
Data Validation
Update Data:
Data Validation
Data are stored to
MGMS.DB here
Update Data: Input Data
ACK
Store Data: Active Power (f)
ACK
sd Reserve Verification
Request Data: Reserve Verification
Calculations:
Reserve Verification
Update Data: Reserve Verification
Store Data: Reserve Verification
ACK
loop
[Every Cycle]
2. MGMS Subscription
Event Report [Alternative Scenario 1]
Request Data:
Active Power (f)
Internal Calculations
IF Event/
Threshold
Update Data:
Active Power (f)
POST Data: Active Power (f)
0..*
sd StoreNewData
Update Data:
Active Power (f)
3. MGMS request Report
[Alternative Scenario 2]
sd SendRequestedData
0..*
GET Data:
Active Power (f)
POST Data: Active Power (f)


uc Validation of FCR by Microgrid Operator
MGMS
AMS.DA
Data transmission
Data transition
MGMS.DT
MGMS.DM
Data reading
Data storing
MGMS.DBM
Data validation
Data acquisition
MGMS.DP
MGMS.DA
CEMS
Data processing
Data transmission
Signals acquisition
CEMS
IED.SM

3 Step by Step Analysis of Use Case

Scenatio No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
1.NS1: Reserve Notification	AMS	AMS has received a bid approval from the Reserve Market.	MGMS has supplied AMS with available flexibility and AMS bids these resources on a hourly Reserve Market.	MGMS has sent the Reserve Notification to all necessary resources.
2. NS2: Frequency control	IED.FC	Deviation of frequency more than threshold.	Reserve Notification was acknowledged by IED.FC.	Control action was taken to decrease frequency deviation.
3. NS3: Reserve Verification	MGMS	Periodically (e.g. every minute, every hour)		Data of microgrid flexibility activated and maintained for FCR is stored by MGMS.DBM.
4.AS1: Event based subscription report	IED.FC	IED.SM generates the report about FCR maintenance and activation if FCR activation took place.	MGMS has subscribed for time-stamped flexibility capacity used for FCR.	Data of microgrid flexibility activated for FCR is stored by MGMS.DBM.
5. AS2: Request based report	AMS.DT	DER.FC has received a request about validation report from AMS.	MGMS was requested verification report.	Data of microgrid flexibility activated and maintained for FCR is stored by MGMS.DBM.
6.AS3: Report from IED.FC failed	MGMS.DT	No data were acquired after a timeout or request.	Request was sent to IED.FC or timeout is settled in case of subscription.	Data of microgrid flexibility activated and maintained for FCR is **not** stored by MGMS.DBM

Steps – Normal Sequence

Scenario Name :	*1.NS1: Reserve Notification*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Update Data: Reserve Notification	AMS.DA sends an updated Reserve Notification report to AMS.DM	AMS.DA	AMS.DM	Report [Reserve Notification]	TT1 TR4 SA2 A0
2	Send Data: Reserve Notification	AMS.DM sends Reserve Notification report to AMS.DT	AMS.DM	AMS.DT	Request to send [reserve notification]Report [reserve notification]	TT1 TR4 SA2 A0
3	POST Data: reserve Notification	AMS.DT publishes a report to MGMS.DA	AMS.DT	MGMS.DA	Report [reserve notification]	TT1 TR4 SA2 A0
4	Request Data: Data Validation	MGMS.DA transfers an input data to MGMS.DP	MGMS.DA	MGMS.DP	Send signal [data validation] Report [input data]	TT1 TR4 SA2 A0
5	Calculations: Data validation	MGMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	MGMS.DP	MGMS.DP	No information exchange	
6	Update Data:	MGMS.DP returns the processed data to MGMS.DA	MGMS.DP	MGMS.DA	Report [data	TT1 TR4 SA2 A0

	Data Validation				validation] Alarm signal [data validation]	
7	Store Data: Reserve Notification	MGMS.DA transfers the processed data to MGMS.DBM to store them	MGMS.DA	MGMS.DBM	Store signal [reserve notification] Report [reserve notification]	TT1 TR4 SA2 A0
8	Send Data: Reserve Notification	MGMS.DM requests MGMS.DT to send reserve notification to IED.FC	MGMS.DM	MGMS.DT	Send signal [reserve notification] Report [reserve notification]	TT1 TR4 SA2 A0
9	POST Data: Reserve Notification	MGMS.DT sends data to IED.FC	MGMS.DT	IED.FC	Report [reserve notification]	TT1 TR4 SA2 A0

Scenario Name :	*2.NS2:Frequency control*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Periodically Request Data: Frequency Measurements	IED.FC samples data from IED.SM	IED.FC	IED.SM	Request signal [frequency measurements]	TT4, TR4, SA1, A5
2	Update Data: Frequency Measurements	IED.SM updates the data	IED.SM	IED.FC	Report [frequency measurements]	TT4, TR4, SA1, A5
3	Periodically Calculations: Frequency Control	IED.FC processes and analyses the data, then generates a new report that will be transmitted to the MGMS.DA	IED.FC	IED.FC	No information exchange	

Scenario Name :	*3.NS3: Reserve Verification*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Periodically Request Data: Active Power (f)	IED.FC requests the data from IED.SM	IED.FC	IED.SM	Request signal [active power (f)]	TT1 TR4 SA4 A0
2	Data Update: Active Power (f)	IED.FC samples data from IED.SM	IED.SM	IED.FC	Report [active power (f)]	TT1 TR4 SA4 A0
3	POST Data: Active Power (f)	IED.FC publishes a report, that is acquired by MGMS.DA	IED.FC	MGMS.DA	Report [active power (f)]	TT1 TR4 SA4 A0
4	Request Data: Processed Data	MGMS.DA transfers an input data to MGMS.DP	MGMS.DA	MGMS.DP	Request to process data [active power (f)] Report [active	TT1 TR4 SA4 A0

					power (f)]	
5	Calculations: Data validation	MGMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	MGMS.DP	MGMS.DP	No information exchange	
6	Update Data: Processed Data	MGMS.DP returns the processed data to MGMS.DA	MGMS.DP	MGMS.DA	Report [active power (f)]	TT1 TR4 SA4 A0
7	Send Data: Active Power (f)	MGMS.DA transfers the processed data to MGMS.DM	MGMS.DA	MGMS.DM	Report [active power (f)]	TT1 TR4 SA4 A0
8	Store Data: Active Power (f)	MGMS.DM transmits the report checked by MGMS.DP to MGMS.DBM	MGMS.DM	MGMS.DBM	Request to store data [active power (f)] Report [active power (f)]	TT1 TR4 SA4 A0
9	Request Data: Reserve Verification	MGMS.DM request Reserve Verification report	MGMS.DM	MGMS.RV	Request signal [reserve verification] Report [active power (f)]	TT1 TR4 SA4 A0
10	Calculations: Reserve Verification	MGMS.DP creates Verification Notification	MGMS.RV	MGMS.RV	No information exchange	
11	Update Data: Reserve Verification	MGMS.DP returns the report data to MGMS.DM	MGMS.DP	MGMS.DM	Report [reserve verification]	TT1 TR4 SA4 A0
12	Store Data: Reserve Verification	MGMS.DM transfers the processed data to MGMS.DBM	MGMS.DM	MGMS.DT	Request signal to send data [reserve verification] Report [reserve verification]	TT1 TR4 SA4 A0

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :		*4. AS1: Event based subscription report*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
2a1	Event based/Threshold crossed Data Update: Active Power (f)	IED.SM processes and analyses the data, then generates a new report that will be transmitted to the IED.FC if threshold was crossed	IED.SM	IED.FC	Report [active power (f)]	TT1 TR4 SA4 A0

Scenario Name :		*5. AS2: Request based report*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1-2a1	Request Data: Active Power (f)	MGMS.DA requests a data report from IED.FC	MGMS.DA	IED.FC	Request signal [active power (f)]	
1-2a2	POST	IED.FC sends the data to	IED.FC	MGMS.DA	Report [active power	TT1 TR4 SA4 A0

	Data: Active Power (f)	MGMS.DA			(f)]	

Scenario Name :	*6. AS3: Report from IED.FC failed*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
3a1	Data acquisition fails	IED.FC could not transmit a report to MGMS.DA because An error occurred between end points	IED.FC	MGMS.DA	NONE	
3a2	Data notification	MGMS.DA notifies MGMS.DT that some IED.FC has not respond	MGMS.DA	MGMS.DT	Notification, Microgrid ID	
3a3	Data acquisition	MGMS.DT sends request to MGMS.DA	MGMS.DT	MGMS.DA	State request	

FCR (Aggregator) detailed

1 Description of the Use Case

Name of Use Case

Operation of Frequency Containment Reserve (FCR) from the viewpoint of Aggregator

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	***Domain Expert*** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1	22.11.2017	Matti Aro (VTT)	Primary	Power grid operations	First draft	Draft for review
Version 0.2 Revised version of 0.1 (adjusted terminology and architecture)	5.01.2018	Matti Aro (VTT)	Primary	Core team	Second draft	Draft for review
Version 0.3 (Harmonizing use case with the sequence diagram)	11.04.2018	Matti Aro (VTT)	Primary	Core team	Third draft	Draft for review
Version 0.4 Detailed terminology and sequence diagrams	24.04.2018	Matti Aro (VTT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	***Higher Level Use Case***
Monitoring	Flexibility management

Maturity of Use Case *– in business operation, realized in demonstration project, , realised in R&D, in preparation, visionary*
Under development
Prioritization
High
Generic, Regional or National Relation
Generic
View *- Technical / Business*
Technical
Further Keywords for Classification

Operation of FCR, frequency containment, power grid management, flexibility market

Scope and Objectives of Use Case

Scope of Function
Operation of FCR is part of more generic scheme - Power grid management. After operating in FCR a report of operation of reserve target is needed for verification of realized adjustments.
Objectives of Function
Objective of FCR is to maintain the necessary balance between power production and consumption. FCR verificationis meant to verify that promised/contracted adjustments have been made.

Narrative of Use Case

Short description *– max 3 sentences*
This use case demonstrates the role that Aggregator plays in FCR operations.
Complete description
Acting on FCR market (Reserve Market Platform (RMP)) poses a need for continuous monitoring of load/production unit control in order to ascertain the correct functioning of the unit. The load/production unit should react to the fluctuations in the frequency of electricity and therefore monitoring is a necessity for verification. DSO is the user of this reserve and flexible resource owner is the provider. Trading is done in the Reserve Market Platform (RMP) where Aggregators leave bids and DSO acceptes them in the price order. Aggregator acts as an intermediary between Microgrid Operator (MO) and RMP. Aggregator's goals in FCR validation are: • aggregate a portfolio of DERs and provide flexible capacity to RMP; • fulfill DSO's requirements of providing the data about load/production unit control signal; • get data from DER owner.

Actors: Detailed Terminology

Actor Name	***Actor Type***	***Actor Description***	***Further information specific to this Use Case***
AMS	IT system	Aggregator Management System	
AMS.DA	Function	Aggregator Management System Data Acquisition	
AMS.DM	Function	Aggregator Management System Data Management	
AMS.DT	Function	Aggregator Management System Data Transmission	
AMS.TS	Function	Aggregator Management System Trading System	
AMS.DB	Database	Aggregator Management System Database	
MGMS	IT system	Microgrid Management System	
MGMS.DA	Function	Microgrid Management System Data Acquisition	
MGMS.DT	Function	Microgrid Management System Data Transmission	
DMS	IT System	Distribution Management System	
DMS.DA	Function	Distribution Management System Data Acquisition	
DMS.DT	Function	Distribution Management System Data Transmission	

RMP	IT Platform	Reserve Market Platform	
RMP.DA	Function	Reserve Market Platform Data Acquisition	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	***Reference** – law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs is required as input of the EMS.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***	**Post-conditions**
AMS		The system is up and running.		
MGMS		The system is up and running.		
RMP		The system is up and running.		

Referenced Standards and / or Standardization Committees (if available)

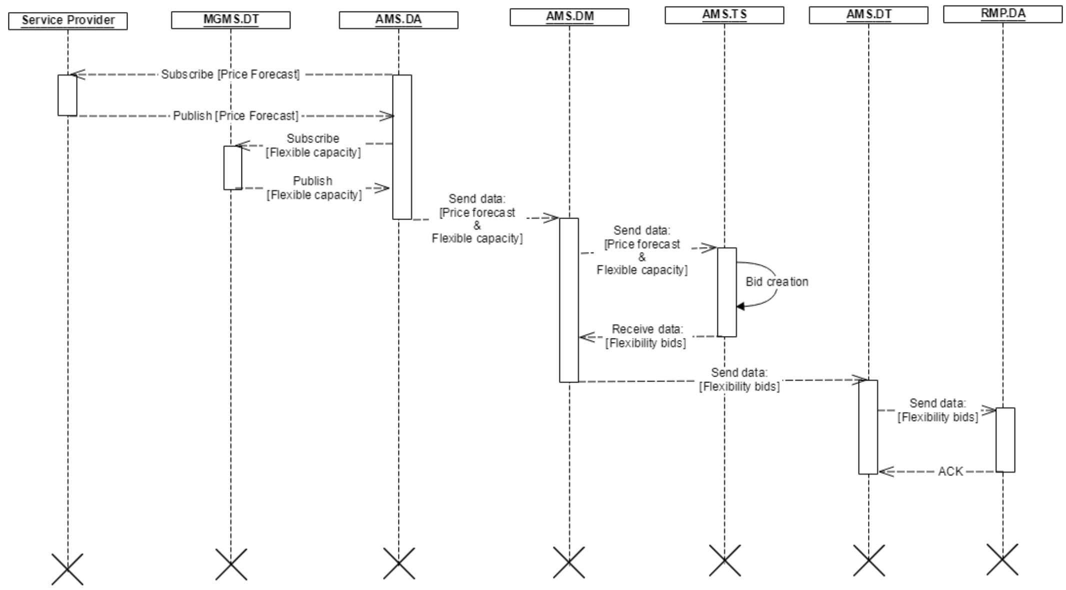
Relevant Standardization Committees	***Standards supporting the Use Case***	***Standard Status***

General Remarks

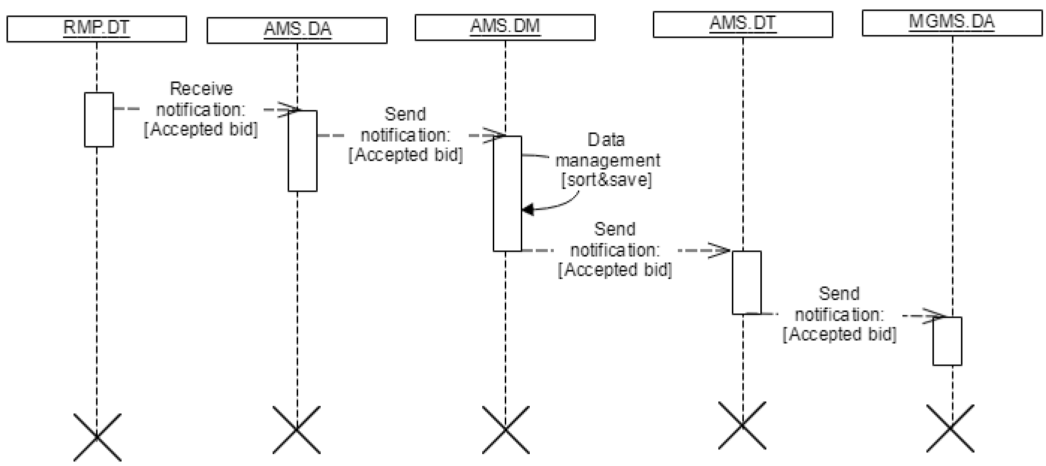
General Remarks

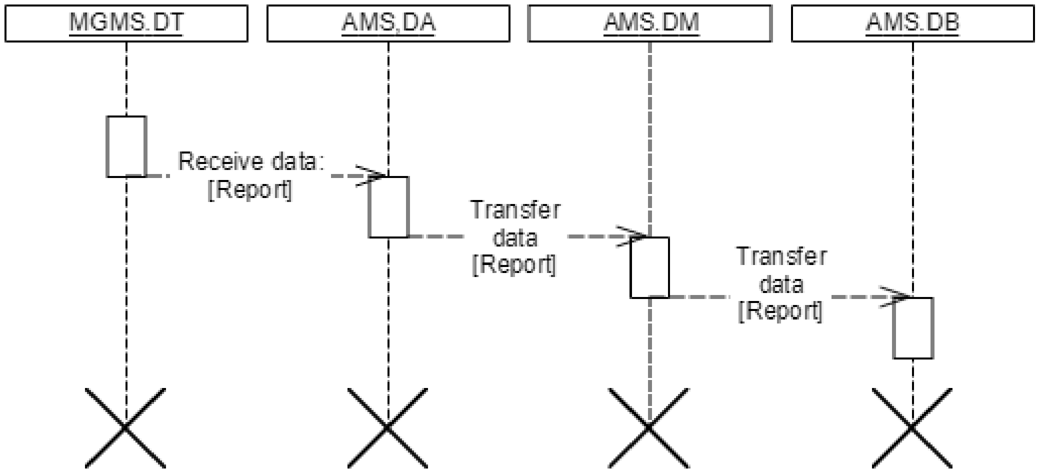
2 Drawing or Diagram of Use Case

Sequence Diagram - FCR (Agg.) - PS1

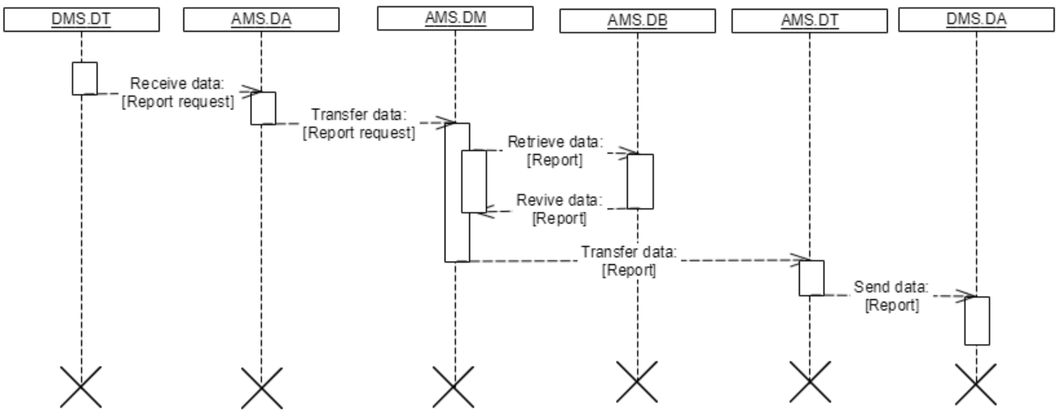


Sequence Diagram - FCR (Aggregator) - PS2





Sequence Diagram - FCR (Agg.) - AS1



3 Step by Step Analysis of Use Case

Scenatio No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1 Aggregator provides capacity bids to Reserve Market Platform.	AMS	Periodically before gate closure.	Microgrid(s) has flexible resources to be provided in RMP.	Bids are sent to RMP
Primary scenario 2 Aggregators bid(s) get accepted in RMP.	AMS	System Operator (DSO) acceptes bid(s) from RMP.	Aggregator has provided bid(s) to RMP.	Information about accepted bid(s) is sent to MO
Primary scenario 3 Aggregator aggregates reports from (possibly) several microgrids about load/production unit's functioning and stores it to Database in case of a need for verification.	AMS	Operating time (hour/year) has ended.	Bids have been accepted and DERs have been acting as a reserve	Time-series of forecasted powers and time-series of actual powers have been stored in Aggregators Database.
Alternative scenario 1 System Operator (DSO) wants a verification of the operation of	AMS	System Operator (DSO) sends verification request to Aggregator about past operations of active	(At least) Some of the DERs in Aggregators portfolio have been acting as reserves in	Time-series of forecasted powers and time-series of actual powers have been sent for verification to

reserves that have been active.		reserves.	DSOs reserve	DSO

Steps – Normal Sequence

Scenario Name :	*PS1: Aggregator provides capacity bids to Reserve Market Platform.*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1a	Forecast update Periodically	Service Provider sends price forecasts to AMS.DA	SP	AMS.DA	Price forecast	TT1, TR4, SA4, A0
1b	Flexibility report Periodically	MGMS.DT sends periodically a report of the flexibility to AMS.DA	MGMS.DT	AMS.DA	Time-series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s])	TT1, TR4, SA4, A0
2	Data storage	AMS.DA sends received flexibility report to AMS.DM	AMS.DA	AMS.DM	Time-series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s])	TT1, TR4, SA2, A0
3	Bid creation	AMS.DM aggregates information from all flexible resources that it has for the next time period and creates flexibility bids out of them to be send to RMP.	AMS.DM	AMS.DT	Time-series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA2, A0
4	Bid(s) is sent to RMP	AMS.DT sends the offer to RMP.DA	AMS.DT	RMP.DA	Time-series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA4, A0

Scenario Name :	*PS2: Aggregators bid(s) get accepted in RMP.*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Bid is accepted	RMP sends notification to AMS that the bid is accepted as a reserve for Frequency Containment	RMP.DT	AMS.DA	Notification of accepted bid (ID, time, price)	TT1, TR4, SA4, A0
2	Notification is received	AMS.DA sends the notification to Data Management	AMS.DA	AMS.DM	Notification of accepted bid (ID, time, price)	TT1, TR4, SA2, A0
3	Notification is sent to Data Management	Data Management separetes the DERs of different microgrids from the bid to be	AMS.DM	AMS.DT	Notification of accepted bid (ID, time, price)	TT1, TR4, SA2, A0

		sent to corresponding MOs.				
4	Reports to different microgrids is created	AMS.DT sends reports to those microgrids that were included in the bid that got accepted	AMS.DT	MGMS.DA	Notification of accepted bid (ID, time, price)	TT1, TR4, SA4, A0

Scenario Name :	*PS3: Aggregator aggregates reports from (possibly) several microgrids about load/production unit's functioning and stores it to Database in case of a need for verification.*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Data about operation of reserve targets are periodically retrieved from the MGMS database	AMS.DA receives a report from MGMS.DT	MGMS.DT	AMS.DA	Time-series of forecasted powers and time-series of actual powers	TT1, TR4, SA4, A0
2	Data is received from (possibly) several microgrids	AMS.DA transfers the report to AMS.DM	AMS.DA	AMS.DM	Time-series of forecasted powers and time-series of actual powers	TT1, TR4, SA2, A0
3	Data is transferred to AMS.DM	Data is stored in AMS.DB	AMS.DM	AMS.DB	Time-series of forecasted powers and time-series of actual powers	TT1, TR4, SA2, A0

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	*AS1: System Operator (DSO) wants a verification of the operation of reserves that have been active.*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Need for FCR verification is realized	DMS.DT sends a request for FCR verification	DMS.DT	AMS.DA	Request for FCR report	TT1, TR4, SA4, A0
2	Request is received from DMS.DT	AMS.DA transfers the request to AMS.DM	AMS.DA	AMS.DM	Request for FCR report	TT1, TR4, SA2, A0
3	Request is transferred to AMS.DM	AMS.DM retrieves the report from Database	AMS.DM	AMS.DB	Request for FCR report	TT1, TR4, SA2, A0
4	Report is received from Database	AMS.DM receives the report from Database	AMS.DB	AMS.DM	FCR report (Time-series of forecasted powers and time-series of actual powers)	TT1, TR4, SA2, A0
5	Report is transferred to AMS.DM	AMS.DM transfes the report in question to AMS.DT	AMS.DM	AMS.DT	FCR report (Time-series of forecasted powers and time-series of actual powers)	TT1, TR4, SA2, A0
6	Report is transferred to AMS.DT	AMS.DT sends the report to DSO (DMS.DA)	AMS.DT	DMS.DA	FCR report (Time-series of forecasted powers and time-series of actual powers)	TT1, TR4, SA4, A0

FCR (TSO) detailed

1 Description of the Use Case

Name of Use Case

Frequency Containment Reserve by TSO

Version Management

Changes / Version	*Date*	*Name Author(s) or Committee*	**Domain Expert** Primary, additional	*Area of Expertise / Domain / Role*	*Title*	*Approval Status* *draft, for comments, for voting, final*
0.1	22.11.2017	Sami Repo (TUT)	Primary	Core team	First draft	Draft for review
0.2 Harmonizing use case with the sequence diagram	12.4.2018	Matti Aro (VTT)	Primary	Core team	Second draft	Draft for review
0.3 Technical requirements, refocusing to TSO	20.04.2018	Aleksei Mashalkov (LUT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	*Link*	*Conditions (limitations) of Use*

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	*Higher Level Use Case*
Control	Frequency Containment

Maturity of Use Case – *in business operation, realized in demonstration project, realised in R&D, in preparation, visionary*
Realized in R&D
Prioritization
Medium
Generic, Regional or National Relation
Generic
View - *Technical / Business*
Technical
Further Keywords for Classification

Frequency Containment, Reserve Market, Flexibility Management

Scope and Objectives of Use Case

Scope of Function
This use case consists of maintenance, activation and verification of Frequency Containment Reserve by Transmission System Operator (TSO)
Objectives of Function
This use case enables TSO to maintain and operate Frequency Containment Reserve with low-cost reserves of microgrids in order to continuously maintain the necessary balance between power consumption and production.

Narrative of Use Case

Short description *– max 3 sentences*
Transmission System Operator purchases flexible capacity from Reserve Market Platform in order to maintain the power balance in the grid. Afterwards, the reserve owners send verification of the regulation to TSO via Aggregator.
Complete description
This use case illustrates a scenario, where TSO uses low-cost reserves of microgrids as a Frequency Containment Reserve (FCR). In these case TSO: • determines how much Frequency Containment Reserve (FCR) it will need for the future - **Reserve Allocation** • acquires that FCR from Reserve Market Platform (RMP) - **Reserve Notification** • monitors the operation of its reserve targets - **Reserve Verification** TSO is represented as energy management system (EMS). It interacts with reserve market platform (RMP) and aggregator management system (AMS).

Actors: Detailed Terminology

Actor Name *see Detailed Terminology List*	***Actor Type*** *see Detailed Terminology List*	***Actor Description*** *see Detailed Terminology List*	***Further information specific to this Use Case***
EMS	System	Energy Management System	
EMS.DA	Function	Energy Management System Data Acquisition	
EMS.DT	Function	Energy Management System Data Transmission	
EMS.DM	Function	Energy Management System Data Management	
EMS.RV	Function	Energy Management System Reserve Verification	
EMS.RA	Function	Energy Management System Reserve Allocation	
EMS.DBM	Function	Energy Management System Data Base Management	
RMP	Market Platform	Reserve Market Platform	
RMP.DA	Function	Reserve Market Platform Data Acquisition	
RMP.DMB	Function	Reserve Market Platform Data Base Management	
RMP.DM	Function	Reserve Market Platform Data Management	
RMP.DT	Function	Reserve Market Platform Data Transmission	
RMP.MO	Function	Reserve Market Platform Market Operations	

RMP.MOP	Function	Reserve Market Platform Merit Order Placement	
RMP.DP	Function	Reserve Market Platform Data Processing	
AMS	System	Aggregator Management System	
AMS.DM	Function	Aggregator Management System Data Management	
AMS.DP	Function	Aggregator Management System Data Processing	
AMS.DT	Function	Aggregator Management System Data Transmission	
AMS.DBM	Function	Aggregator Management System Data Base Management	
DMS	System	Distribution Management System	
DMS.DT		Distribution Management System Data Transmission	
DMS.DM		Distribution Management System Data Management	
DMS.SF		Distribution Management System State Forecast	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	***Impact of Issue on Use Case***	**Reference** – *law, standard, others*

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	***Triggering Event***	***Pre-conditions***	***Assumption***	**Post-conditions**
AMS		The system is up and running		
EMS		The system is up and running		
RMP		The platform is up and running		

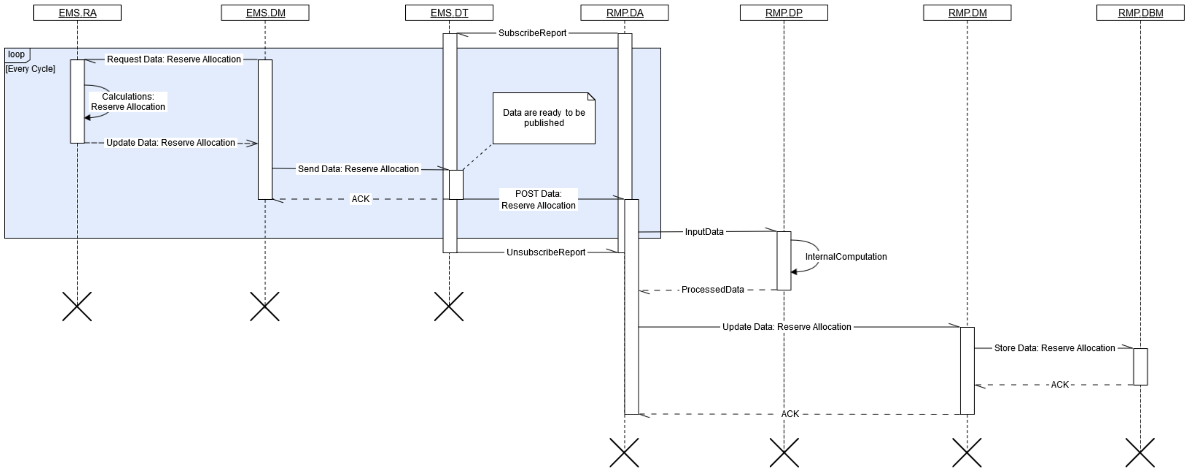
Referenced Standards and / or Standardization Committees (if available)

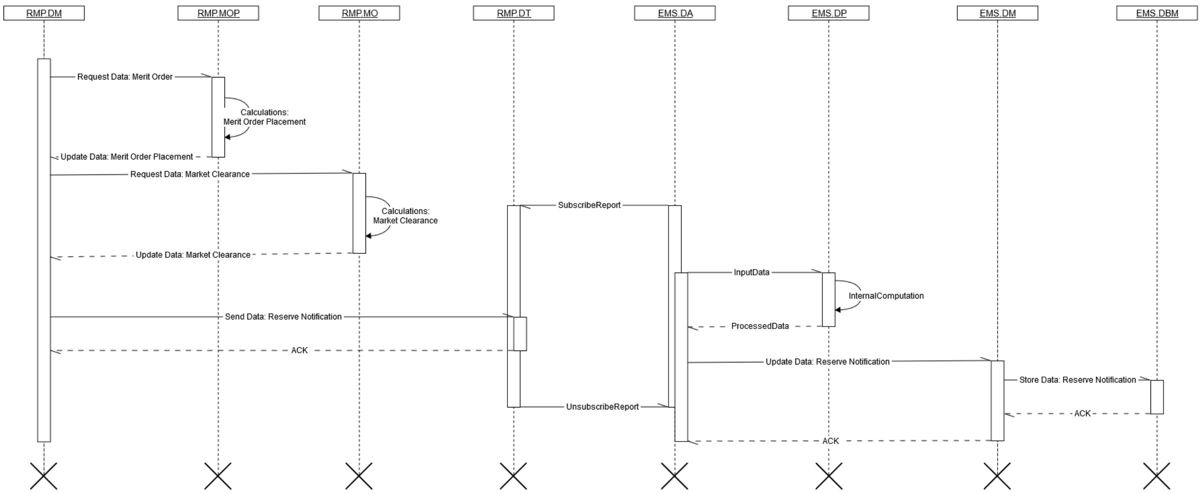
Relevant Standardization Committees	***Standards supporting the Use Case***	***Standard Status***

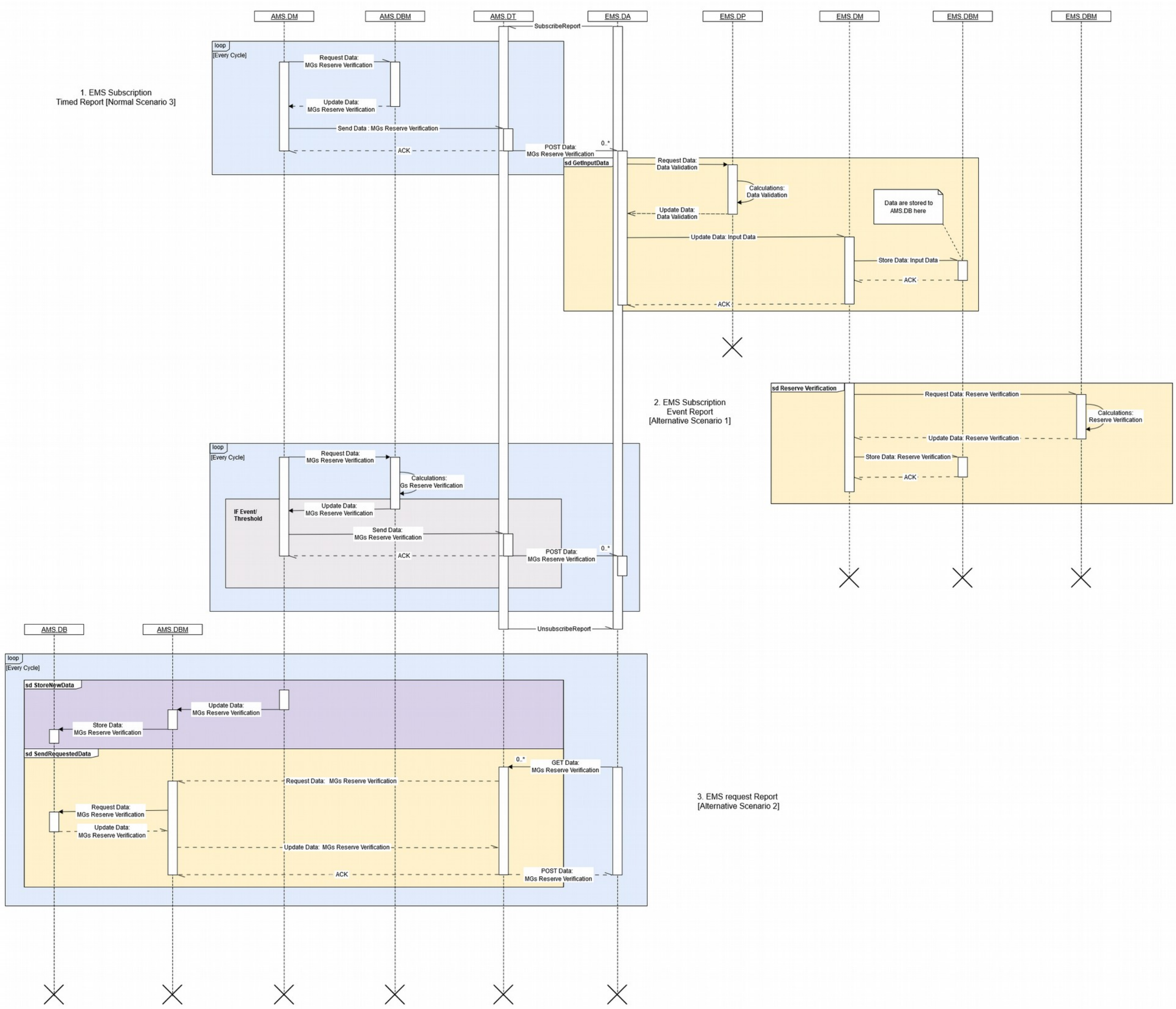
General Remarks

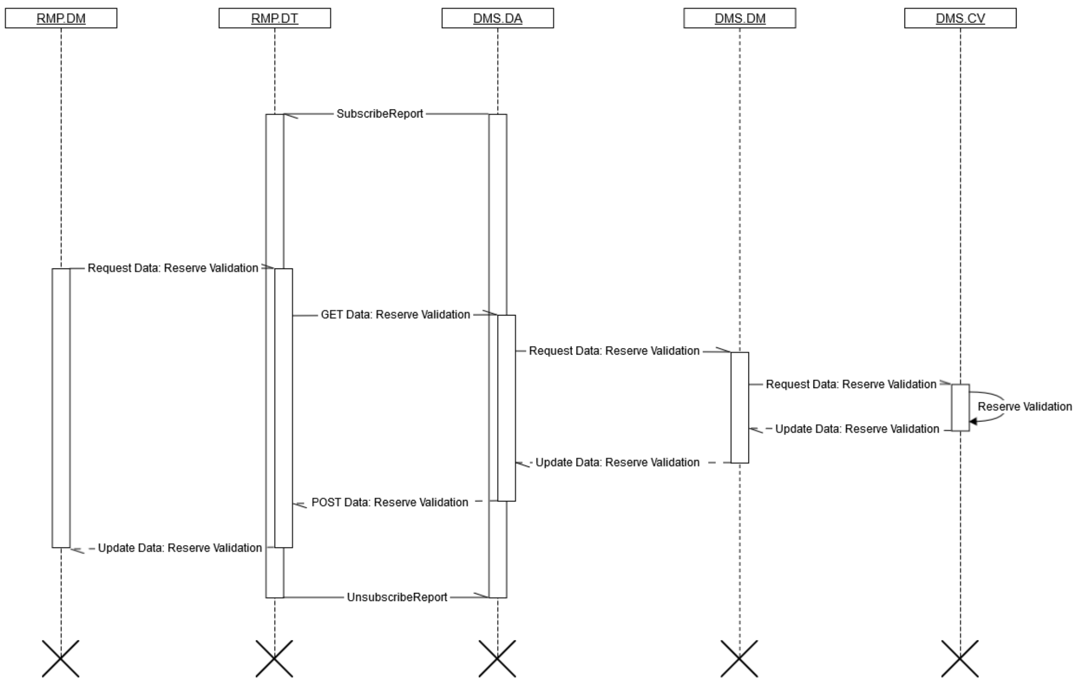
General Remarks

2 Drawing or Diagram of Use Case






AMS.DM
AMS.DBM
AMS.DT
EMS.DA
EMS.DP
EMS.DM
EMS.DBM
EMS.DBM
SubscribeReport
1. EMS Subscription
Timed Report [Normal Scenario 3]
loop
[Every Cycle]
Request Data: MGs Reserve Verification
Update Data: MGs Reserve Verification
Send Data : MGs Reserve Verification
ACK
POST Data: MGs Reserve Verification
sd GetInputData
Request Data: Data Validation
Calculations: Data Validation
Update Data: Data Validation
Data are stored to AMS.DB here
Update Data: Input Data
Store Data: Input Data
ACK
sd Reserve Verification
Request Data: Reserve Verification
Calculations: Reserve Verification
Update Data: Reserve Verification
Store Data: Reserve Verification
2. EMS Subscription
Event Report
[Alternative Scenario 1]
IF Event/ Threshold
UnsubscribeReport
AMS.DB
AMS.DBM
sd StoreNewData
Store Data: MGs Reserve Verification
sd SendRequestedData
GET Data: MGs Reserve Verification
Request Data: MGs Reserve Verification
Update Data: MGs Reserve Verification
3. EMS request Report
[Alternative Scenario 2]


RMP.DM
RMP.DT
DMS.DA
DMS.DM
DMS.CV
SubscribeReport
Request Data: Reserve Validation
GET Data: Reserve Validation
Request Data: Reserve Validation
Request Data: Reserve Validation
Reserve Validation
Update Data: Reserve Validation
Update Data: Reserve Validation
POST Data: Reserve Validation
Update Data: Reserve Validation
UnsubscribeReport

3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1: **Reserve Allocation**	EMS	Periodically before the next market cycle.	TSO requires additional resources for hourly reserve market.	The reserve allocation data is delivered to RMP.
Primary scenario 2: Reserve Notification	RMP	Periodically before the next market cycle.	TSO has allocated the volume of the resources required for hourly reserve market.	TSO is notified about purchased reserves for hourly reserve market.
Primary scenario 3: **Reserve Verification**	AMS	Time based report	TSO has purchased some FCR from the RMP.	TSO has received verification about operation of reserve targets.
Alternative scenario 1: **Reserve Verification**	AMS	Event based report	TSO has purchased some FCR from the RMP.	TSO has received verification about operation of reserve targets.
Alternative scenario 2:Reserve Verification	EMS	Request of the report	TSO has purchased some FCR from the RMP.	TSO has received verification about operation of reserve targets.
Alternative scenario 3:Reserve Notification	RMP	Before the next market cycle RMP request validation from DMS.	The capacity limit for the resources from the specific area is exceeded.	RMP receives validation of resource activation.

Steps – Normal Sequence

Scenario Name :	Primary scenario 1: **Reserve Allocation**					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Request Data: Reserve Allocation	EMS.DM requests Reserve Allocation report from EMS.RA	EMS.DM	EMS.RA	Request signal [reserve allocation]	TT1 TR4 SA2 A0
2	Calculations: Reserve Allocation	EMS.RA calculates Reserve Allocation report	EMS.RA	EMS.RA	No information exchange	
3	Update Data: Reserve Allocation	EMS.RA sends an updated Reserve Allocation report to EMS.DM	EMS.RA	EMS.DM	Report [reserve allocation]	TT1 TR4 SA2 A0
4	Send Data: Reserve Allocation	EMS.DM sends Reserve Allocation report to EMS.DT	EMS.DM	EMS.DT	Request to send [reserve allocation]Report [reserve allocation]	TT1 TR4 SA2 A0
5	POST Data: Reserve Allocation	EMS.DT publishes a report to RMP.DA	EMS.DT	RMP.DA	Report [reserve allocation]	TT1 TR4 SA2 A0
6	Request Data: Data Validation	RMP.DA transfers an input data to RMP.DP	RMP.DA	RMP.DP	Send signal [data validation] Report [input data]	TT1 TR4 SA2 A0
7	Calculations: Data	RMP.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	RMP.DP	RMP.DP	No information exchange	

	validation					
8	Update Data: Data Validation	RMP.DP returns the processed data to RMP.DA	RMP.DP	RMP.DA	Report [data validation] Alarm signal [data validation]	TT1 TR4 SA2 A0
9	Store Data: Reserve Allocation	MGMS.DA transfers the processed data to MGMS.DBM to store them	RMP.DA	RMP.DBM	Store signal [reserve allocation] Report [reserve allocation]	TT1 TR4 SA2 A0

Scenario Name:	Primary scenario 2: **Reserve Notification**					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Request Data: Merit Order List	RMP.DM requests merit order list from RMP.MOP	RMP.DM	RMP.MOP	Request signal [merit order list] Report [Offers]	TT1 TR4 SA2 A0
2	Calculations: Merit Order Placement	RMP.MOP calculates Merit Order List	RMP.MOP	RMP.MOP	No information exchange	
3	Update Data: Merit Order List	RMP.MOP updates Merit Order List for RMP.DM	RMP.MOP	RMP.DM	Report [merit order list]	TT1 TR4 SA2 A0
4	Request Data: Reserve Notification	RMP.DM requests Reserve Notification from RMP.MO	RMP.DM	RMP.MO	Request signal [reserve notification] Report [merit order list]	TT1 TR4 SA2 A0
5	Calculations: Reserve Notification	RMP.MO calculates Reserve Notification	RMP.MO	RMP.MO	No information exchange	
6	Update Data: Reserve Notification	RMP.MO updates Reserve Notification for RMP.DM	RMP.MO	RMP.DM	Report [reserve notification]	TT1 TR4 SA2 A0
7	Send Data: Reserve Notification	RMP.DM sends Reserve Notification report to RMP.DT	RMP.DM	RMP.DT	Request to send [reserve notification]Report [reserve notification]	TT1 TR4 SA2 A0
8	POST Data: reserve Notification	RMP.DT publishes a report to EMS.DA	RMP.DT	EMS.DA	Report [reserve notification]	TT1 TR4 SA2 A0
9	Request Data: Data Validation	EMS.DA transfers an input data to EMS.DP	EMS.DA	EMS.DP	Send signal [data validation] Report [input data]	TT1 TR4 SA2 A0
10	Calculations: Data validation	EMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	EMS.DP	EMS.DP	No information exchange	
11	Update Data: Data Validation	EMS.DP returns the processed data to EMS.DA	EMS.DP	EMS.DA	Report [data validation] Alarm signal [data validation]	TT1 TR4 SA2 A0
12	Store Data: Reserve Notification	EMS.DA transfers the processed data to EMS.DBM to store them	EMS.DA	EMS.DBM	Store signal [reserve notification] Report [reserve notification]	TT1 TR4 SA2 A0

Scenario Name:		Primary scenario 3: ***Reserve Verification***				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Request Data: MGs Reserve Verification	AMS.DM periodically requests the report from AMS.DBM	AMS.DM	AMS.DBM	Request signal [mgs reserve verification]	TT1 TR4 SA2 A0
2	Update Data: MGs Reserve Verification	AMS.DBM transmits an updated report to AMS.DM	AMS.DBM	MGMS.DM	Report [mgs reserve verification]	TT1 TR4 SA2 A0
3	Send Data: MGs Reserve Verification	AMS.DM transfers a report to AMS.DT	AMS.DM	AMS.DT	Send signal to send [mgs reserve verification] Report [mgs reserve verification]	TT1 TR4 SA2 A0
4	POST Data: MGs Reserve Verification	AMS.DT POST a report to AMS.DA	AMS.DT	EMS.DA	Report [mgs reserve verification]	TT1 TR4 SA4 A0
5	Request Data: Data Validation	EMS.DA transfers an input data to EMS.DP	EMS.DA	EMS.DP	Send signal [data validation] Report [input data]	TT1 TR4 SA2 A0
6	Calculations: Data validation	EMS.DP "check routines", that check for correctness, meaningfulness, and security of data that are input to the system.	EMS.DP	EMS.DP	No information exchange	
7	Update Data: Data Validation	EMS.DP returns the processed data to EMS.DA	EMS.DP	EMS.DA	Report [data validation] Alarm signal [data validation]	TT1 TR4 SA2 A0
8	Store Data: Input Data	EMS.DA transfers the processed data to EMS.DBM to store them	EMS.DA	EMS.DBM	Store signal [Input data] Report [data validation]	TT1 TR4 SA2 A0
9	Request Data: Reserve Verification	EMS.DM request Reserve Verification report	EMS.DM	EMS.RV	Request signal [reserve verification] Report [mgs reserve verification]	TT1 TR4 SA4 A0
10	Calculations: Reserve Verification	EMS.DP creates Verification Notification	EMS.RV	EMS.RV	No information exchange	
11	Update Data: Reserve Verification	EMS.DP returns the report data to EMS.DM	EMS.DP	EMS.DM	Report [reserve verification]	TT1 TR4 SA4 A0
12	Store Data: Reserve Verification	EMS.DM transfers the processed data to EMS.DBM	EMS.DM	EMS.DT	Request signal to send data [reserve verification] Report [reserve	TT1 TR4 SA4 A0

					verification]	

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	Alternative scenario 1: **Reserve Verification**					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
2a1	Event based/Threshold crossed Data Update: MGs Reserve Verification	AMS.DBM processes and analyses the data, then generates a new report that will be transmitted to the AMS.DM if threshold was crossed	AMS.DBM	AMS.DM	Report [mgs reserve verification]	TT1 TR4 SA4 A0

Scenario Name :	Alternative scenario 2: ***Reserve Verification***					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1-4a1	GET Data: MGs Reserve Verification	EMS.DA requests a data report from AMS.DT	EMS.DA	AMS.DT	Request signal [mgs reserve verification]	TT1 TR4 SA4 A0
1-4a2	Request Data: MGs Reserve Verification	AMS.DT requests MGs Reserve Verification from AMS.DBM	AMS.DT	AMS.DBM	Request signal [mgs reserve verification]	TT1 TR4 SA2 A0
1-4a3	Request Data: MGs Reserve Verification	AMS.DBM retrieves the data from AMS.DB	AMS.DBM	AMS.DB	Request signal [mgs reserve verification]	TT1 TR4 SA2 A0
1-4a4	Update Data: MGs Reserve Verification	AMS.DM retrieves the data from AMS.DB	AMS.DB	AMS.DBM	Report [mgs reserve verification]	TT1 TR4 SA2 A0

Scenario Name :	Alternative scenario 3: **Reserve Notification**					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
*Confirmation messages are currently not included in the scenario						
1	Request Data: Reserve Validation	RMP.DM requests Reserve Validation report from RMP.DA	RMP.DM	RMP.DA	Request signal [reserve validation] Report [offers list]	TT1 TR4 SA2 A0
2	GET Data: Reserve Validation	RMP.DA requests Reserve Validation report from DMS.DT	RMP.DA	DMS.DT	Request signal [reserve validation] Report [offers list]	TT1 TR4 SA4 A0
3	Request Data: Reserve Validation	DMS.DT imports the data to DMS.DM	DMS.DT	DMS.DM	Request signal [reserve validation] Report [offers list]	TT1 TR4 SA2 A0
4	Request Data: Reserve Validation	DMS.DM requests Reserve Validation report from DMS.CV	DMS.DM	DMS.CV	Request signal [reserve validation]	TT1 TR4 SA2 A0

					Report [offers list]	
5	Calculations: Reserve Validation	DMS.CV calculates Reserve Validation report	DMS.CV	DMS.CV	No information exchange	
6	Update Data: Reserve Validation	DMS.RA sends an updated Reserve Validation report to DMS.DM	DMS.CV	DMS.DM	Report [reserve validation]	TT1 TR4 SA2 A0
7	Send Data: Reserve Validation	DMS.DM sends Reserve Validation report to DMS.DT	DMS.DM	DMS.DT	Request to send [reserve validation]Report [reserve validation]	TT1 TR4 SA2 A0
8	POST Data: Reserve Validation	DMS.DT publishes a report to RMP.DA	DMS.DT	RMP.DA	Report [reserve validation]	TT1 TR4 SA4 A0
9	Update Data: Reserve Validation	RMP.DA updates a report to RMP.DM	RMP.DA	RMP.DM	Report [reserve validation]	TT1 TR4 SA2 A0

DSO flexibility (Microgrid Operator) detailed

1 Description of the Use Case

Name of Use Case

DSO requests flexibility service (from the viewpoint of MO)

Version Management

Changes / Version	***Date***	***Name Author(s) or Committee***	**Domain Expert** Primary, additional	***Area of Expertise / Domain / Role***	***Title***	***Approval Status*** *draft, for comments, for voting, final*
Version 0.1	21.11.2017	Author: Matti Aro (VTT)	Primary	Power grid operations	First draft	Draft for review
Version 0.2 Revised version of 0.1 (adjusted terminology and architecture)	5.1.2018	Matti Aro (VTT)	Primary	Core team	Second draft	Draft for review
Version 0.3 Changes based on reviews	18.1.2018	Matti Aro (VTT)	Primary	Core team	Third draft	Draft for review
Version 0.4 Harmonizing Detailed UC with sequence diagram	22.3.2018	Matti Aro (VTT)	Primary	Core team	Fourth draft	Draft for review
Version 0.5 Detailed sequence diagrams and terminology	24.4.2018	Matti Aro (VTT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	***Link***	***Conditions (limitations) of Use***

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	***Higher Level Use Case***
Control	Flexibility management

Maturity of Use Case – *in business operation, realized in demonstration project, , realised in R&D, in preparation, visionary*
Under development
Prioritisation
High
Generic, Regional or National Relation

Generic
View *- Technical / Business*
Technical
Further Keywords for Classification
Power quality, flexibility services, microgrid management, distributed energy resources

Scope and Objectives of Use Case

Scope of Function
This use case is part of a more general scheme which aims at creating a Data Exchange Platform for managing Distributed Energy Resources. This use case demonstrates how Microgrid Operator (MO) interacts with Aggregator to provide its flexible resources to flexibility market.
Objectives of Function
MO's objective here is to optimally schedule its own resources within Microgrid to achieve maximum flexibility volume to be offered to Market Place via Aggregator, while still maintaining the quality of supply.

Narrative of Use Case

Short description *– max 3 sentences*
This use case demonstrates how MO interacts with Aggregator to provide its flexible capacity to flexibility market.
Complete description
This use case presents the required interfaces for MO to successfully act as a flexible resource provider at flexible markets. The main functionality of acting as a flexible resource holder for MO is to gain profit by using its resources the most optimal way. Loop 0*: MO optimizes its own flexible resources with weather forecasts provided by SP so that a maximum possible amount of flexible resources is available for flexible market. MO then creates a report where it lists its available resources and sends it to Aggregator. → When some of MO's bids get accepted, MO receives information about that from Aggregator and stays ready if the regulation if activated (Conditional Re-Profiling). If regulation is activated, MO receives notification about that from Aggregator and sends control commands to DERs. After the regulation MO sends verification of the executed regulation back to Aggregator.

Actors: Detailed Terminology

Actor Name *see Detailed Terminology List*	***Actor Type*** *see Detailed Terminology List*	***Actor Description*** *see Detailed Terminology List*	***Further information specific to this Use Case***
Sensor	Device	Sensor	
MGMS	IT system	Microgrid Management System	
MGMS.DA	Function	Microgrid Management System Data Acquisition	
MGMS.FF	Function	Microgrid Management System Flexibility Forecast	
MGMS.DT	Function	Microgrid Management System Data Transmission	
MGMS.DM	Function	Microgrid Management System Data Management	
MGMS.SE	Function	Microgrid Management System State Estimation	
MGMS.TS	Function	Microgrid Management System Trading System	
AMS	IT system	Aggregator Management System	

AMS.DA	Function	Aggregator Management System Data Acquisition	
AMS.DM	Function	Aggregator Management System Data Management	
AMS.DT	Function	Aggregator Management System Data Transmission	
IED	Device	Intelligent Electronic Device	
SP	System	Service Provider	
CEMS	System	Customer Energy Management System	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	*Impact of Issue on Use Case*	***Reference** – law, standard, others*
Customer-owned distributed energy resources (DERs) information	Data from customer-owned DERs required by MGMS.	

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
MGMS		The system is up and running		
AMS		The system is up and running		
CEMS		The system is up and running		

Referenced Standards and / or Standardization Committees (if available)

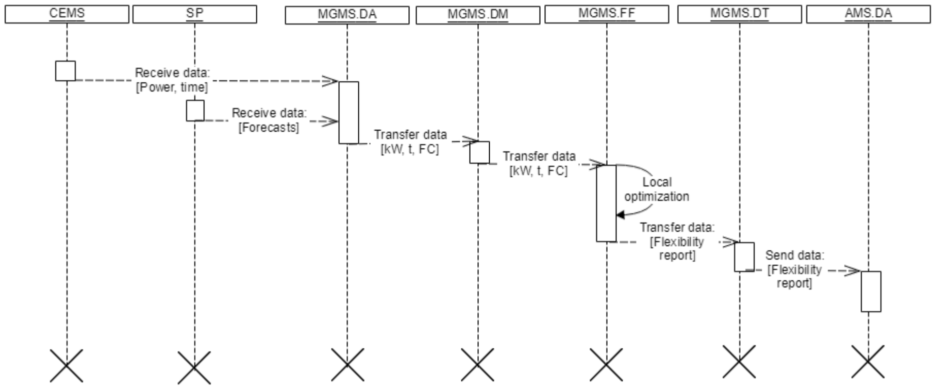
Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

General Remarks

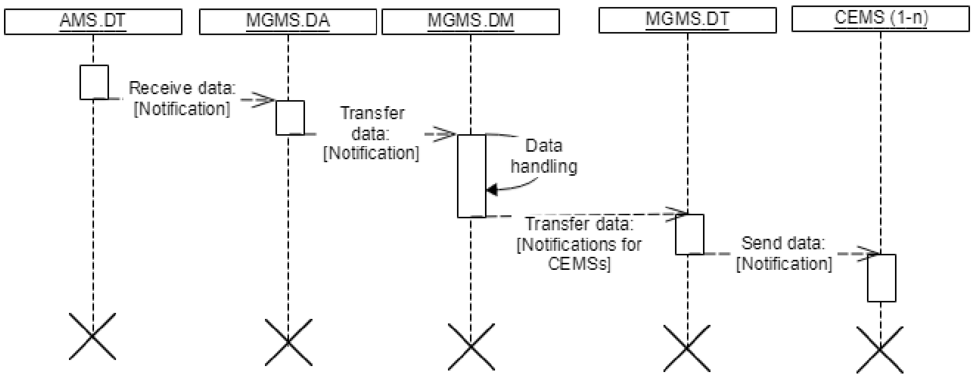
General Remarks
Examples are for Conditional Re-Profiling (CRP)

2 Drawing or Diagram of Use Case

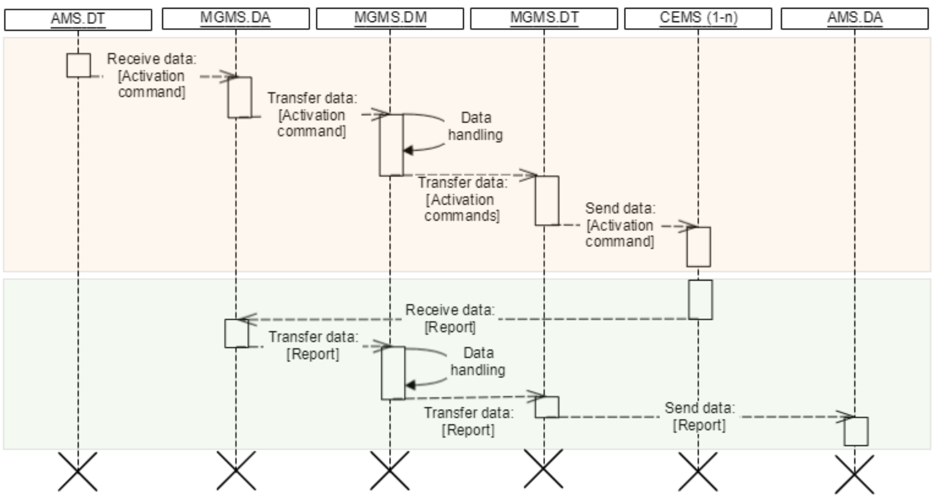
Sequence Diagram - DSO Flexibility (MO) - PS1



Sequence Diagram - DSO Flexibility (MO) - PS2



Sequence Diagram - DSO Flexibility (MO) - PS3



3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1 Flexibility forecast is made and sent to Aggregator	MGMS	MO starts forecasting its flexible capacity	Microgrid has flexible capacity and is willing to offer it to Flexibility Market Platform (FMP)	Flexible capacity has been determined and offered to Aggregator to be sent to FMP
Primary scenario 2 Bid is accepted	MGMS	Bid is accepted on the flexibility markets (in whole or partly)	Microgrid Operator has send flexible resource bids for Aggregator	Bid is accepted in the flexibility markets (in whole or partly) and new flexibility optimizations are created based on updated situation
Primary scenario 3 Activation of regulation	MGMS	MO receives activation notification	MO's bid(s) is accepted on the flexible markets	Aggregator has received report of executed regulation from MO

Steps – Normal Sequence

Scenario Name :	*PS1: Flexibility forecast is made and sent to Aggregator*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Data request Periodically (before deadline for bid submission)	MGMS.DA requests flexible capacity information from its own EMS (logic for determining flexible capacity is out of the scope of HEILA, i.e. every actor does it itself)	CEMS	MGMS.DA	Flexible capacity of CEMS (amount, time)	TT1, TR4, SA4, A0
2	Forecast update Periodically	Service Provider sends weather forecasts to MGMS.DA	SP	MGMS.DA	Weather forecast	TT1, TR4, SA4, A0
3	Data transfer	MGMS.DA transfers the data to MGMS.DM	MGMS.DA	MGMS.DM	Flexible capacity of CEMS (amount, time), weather forecast	TT1, TR4, SA2, A0
4	Data is transfered to MGMS.DM	MGMS.DM passes the data to MGMS.FF	MGMS.DM	MGMS.FF	Flexible capacity of CEMS (amount, time), weather forecast	TT1, TR4, SA2, A0
5	Data is transfered to MGMS.FF	MGMS.FF makes local (microgrid level) optimization. As an output, amount of flexible capacity is determined.	MGMS.FF	MGMS.FF	Local optimization	TT1, TR4, SA2, A0
6	Flexible capacity is determined	MGMS.TS passes the information to MGMS.DT for transmission	MGMS.FF	MGMS.DT	Flexible capacity of Microgrid (amount, time)	TT1, TR4, SA2, A0
7	Information about Flexible capacity is ready to be sent to Aggregator	MGMS.DT sends information about the flexible capacity to Aggregator	MGMS.DT	AMS.DA	Flexible capacity of Microgrid (amount, time)	TT1, TR4, SA4, A0

Scenario Name :	*PS2: Conditional Re-Profiling (CRP) bid is accepted on the market*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Bid or part of it has	MO (MGMS.DA) receives	AMS.DT	MGMS.DA	Regulation information	TT1, TR4,

	been accepted on the market	notification from Aggregator of accepted bid			(up- or down regulation, amount (MW), time period, price, location)	SA4, A0
2	MGMS.DA has received the accepted bid	MGMS.DA transfers the notification to MGMS.DM	MGMS.DA	MGMS.DM	Regulation information (up- or down regulation, amount (MW), time period, price, location)	TT1, TR4, SA2, A0
3	MGMS.DM has received the accepted bid	MGMS.DM reads the notification and generates separate notifications to be sent for proper CEMS's via MGMS.DT	MGMS.DM	MGMS.DT	Regulation information (up- or down regulation, amount (MW), time period, price, location)	TT1, TR4, SA2, A0
4	Accepted bid is separeted into single notifications concerning separate CEMSs	MGMS.DT sends the notifications to proper CEMS's	MGMS.DT	CEMS	Regulation information (up- or down regulation, amount (MW), time period, price, location)	TT1, TR4, SA4, A0

Scenario Name :	*PS3: Activation of CRP regulation*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Notification	MO receives activation notification from Aggregator of accepted bid	AMS.DT	MGMS.DA	Control command	TT3, TR4, SA4, A2
2	MGMS.DA has received notification of accepted bid	MGMS.DA sends the notification to MGMS.DM	MGMS.DA	MGMS.DM	Control command	TT3, TR4, SA2, A2
3	Notification is send to MGMS.DM	MGMS.DM sends the notification to MGMS.DT for distribution to proper CEMSs	MGMS.DM	MGMS.DT	Control command	TT3, TR4, SA2, A2
4	Notification is send to MGMS.DT	MGMS.DT distributes the control commands to CEMSs based on the activation notifications.	MGMS.DT	CEMS	Control command	TT3, TR4, SA4, A2
5	CEMS has executed the regulation	CEMS sends verification of regulation to MGMS.DA	CEMS	MGMS.DA	Verification	TT1, TR4, SA4, A0
6	MGMS.DA has received verification of regulation	MGMS.DA sends verification of regulation to MGMS.DM	MGMS.DA	MGMS.DM	Verification	TT1, TR4, SA2, A0
7	MGMS.DM has received verification of regulation	MGMS.DM creates summary report of verification notifications and sends it to MGMS.DT	MGMS.DM	MGMS.DT	Verification	TT1, TR4, SA2, A0
8	MGMS.DT has received verification of regulation	MGMS.DT sends the summary report of verifications to AMS.DA	MGMS.DT	AMS.DA	Verification	TT1, TR4, SA4, A0

DSO flexibility (Aggregator) detailed

1 Description of the Use Case

Name of Use Case

Version Management

Changes / Version	*Date*	*Name Author(s) or Committee*	***Domain Expert*** Primary, additional	*Area of Expertise / Domain / Role*	*Title*	*Approval Status* *draft, for comments, for voting, final*
0.1	24.11.2017	Author: Ville Tuominen (TUT)	Primary	Core team	First draft	Draft for review
0.2	5.1.2018	Ville Tuominen (TUT)	Primary	Core team	Second draft	Draft for review
0.3 Harmonizing Detailed UC with sequence diagram	9.4.2018	Matti Aro (VTT)	Primary	Core team	Third draft	Draft for review
0.4 Added Sequence Diagrams and Technical Requirements	23.4.2018	Matti Aro (VTT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	*Link*	*Conditions (limitations) of Use*

Relation to Higher Level Use Case	
Cluster - Monitoring, control, market	*Higher Level Use Case*
Control	Flexibility management

Maturity of Use Case
Under development
Prioritisation
High
Generic, Regional or National Relation
Generic
View
Technical

Further Keywords for Classification
Flexibility services, distributed energy resources

Scope and Objectives of Use Case

Scope of Function
This use case describes how Aggregator operates as an intermediary between Microgrid Operator (MO) and Flexibility Market Platform (FMP) (and DSO) enabling MO to participate in the Flexibility Market Platform without direct contact there.
Objectives of Function
Objective of Aggregator here is to participate in the FMP with a portfolio that includes Distributed Energy Resources (DERs) possibly from several microgrids.

Narrative of Use Case

Short description *– max 3 sentences*
Use case describes the role of Aggregator in trading of flexible resources between Microgrid Operator and Flexibility Market Platform.
Complete description
This use case shows required interfaces and functionalities for Aggregator to trade flexibility services between MO and FMP. Microgrid Operator provides its flexible resources to Aggregator who then creates bids out of (possibly) several microgrids. In this use case all the communication and interaction between MO, FMP and DSO is assumed to go through the Aggregator.

Actors: Detailed Terminology

Actor Name *see Detailed Terminology List*	***Actor Type*** *see Detailed Terminology List*	***Actor Description*** *see Detailed Terminology List*	***Further information specific to this Use Case***
AMS	IT system	Aggregator Management System	
AMS.DB	Function	Aggregator Management System Data Base	
AMS.DT	Function	Aggregator Management System Data Transmission	
AMS.DA	Function	Aggregator Management System Data Acquisition	
AMS.TS	Function	Aggregator Management System Trading System	
DMS	IT system	Distribution Management System	
DMS.DA	Function	Distribution Management System Data Acquisition	
DMS.DT	Function	Distribution Management System Data Transmission	
FMP	IT Platform	Flexibility Market Platform	
FMP.DA	Function	Flexibility Market Platform Data Acquisition	
MGMS	IT system	Microgrid Management System	
MGMS.DA	Function	Microgrid Management System Data Acquisition	
MGMS.DT	Function	Microgrid Management System Data Transmission	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	*Impact of Issue on Use Case*	**Reference** – *law, standard, others*

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
AMS		The system is up and running		
DMS		The system is up and running		
MGMS		The system is up and running		

Referenced Standards and / or Standardization Committees (if available)

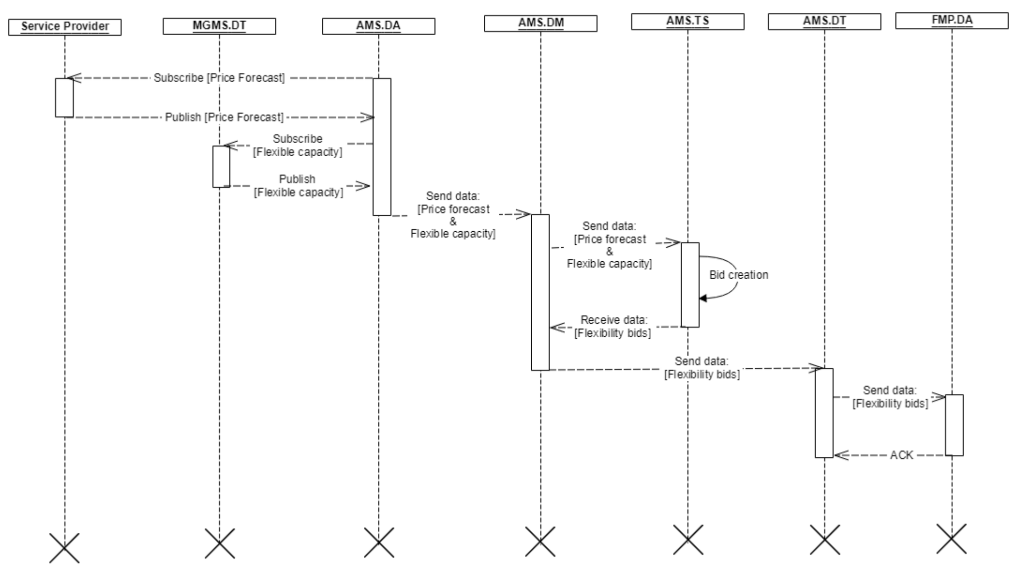
Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

General Remarks

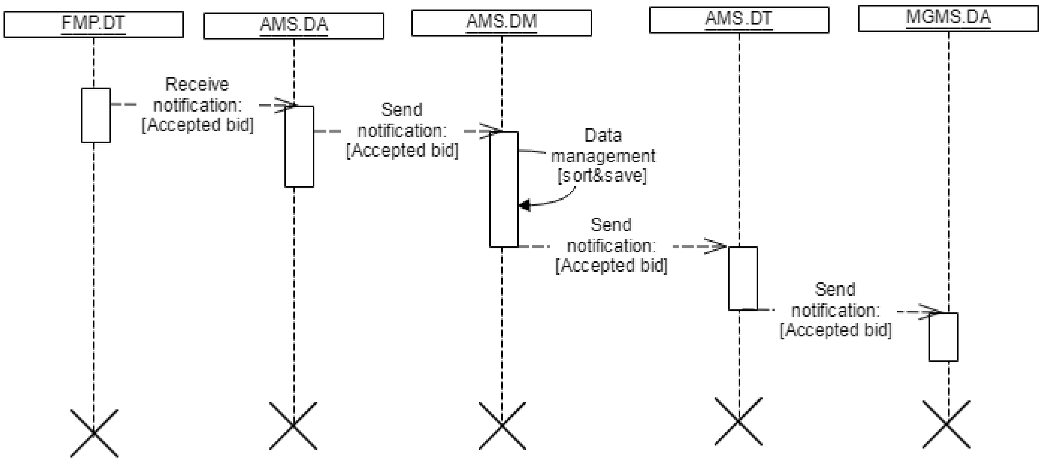
General Remarks
The focus is in Conditional Re-Profiling (CRP)

2 Drawing or Diagram of Use Case

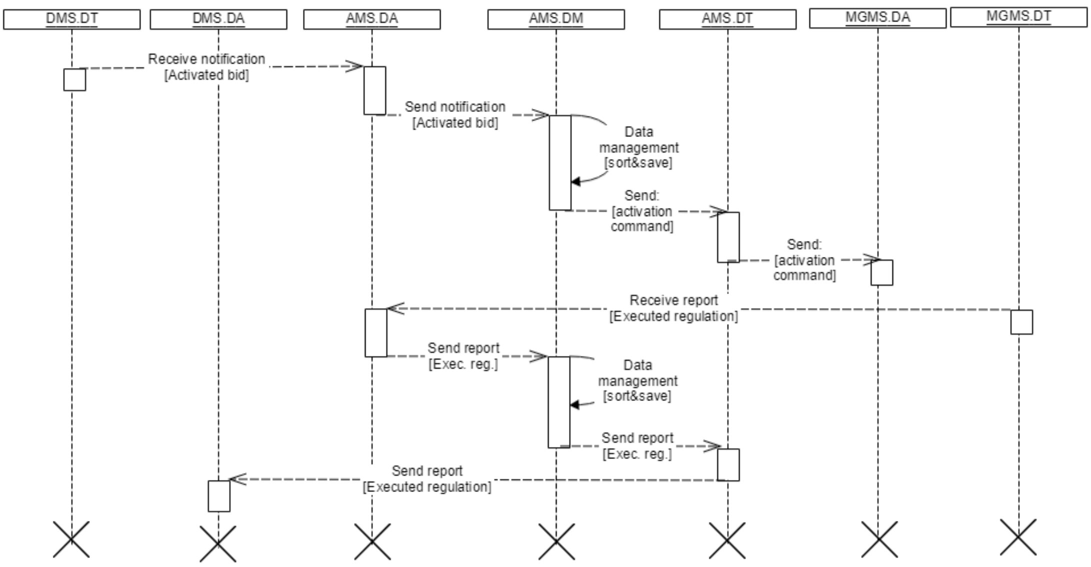
Sequence Diagram - DSO Flexibility (Agg.) - PS1



Sequence Diagram - DSO Flexibility (Agg.) - PS2



Sequence Diagram - DSO Flexibility (Agg.) -PS3



3 Step by Step Analysis of Use Case

Scenario No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
Primary scenario 1: Aggregator provides CRP bids to Flexibility Market Platform (FMP)	AMS.DA	Periodically before gate closure.	Microgrid(s) has flexible resources to be provided in FMP.	Bids are sent to FMP
Primary scenario 2: Aggregator's bid(s) gets accepted in FMP	AMS.DA	Violation of power quality was forecasted by DSO and thus Aggregators bid(s) is accepted from the FMP.	Aggregator has provided bid(s) to FMP.	Information about accepted bid(s) is sent to MO.

Primary scenario 3: Aggregator's bid(s) gets activated by DSO	AMS.DA	Violation of power quality was detected by DSO and activation signal is received by Aggregator.	Accepeted bid(s) and the resources it concerns are ready to act on command	Resources that were reserved are activated.

Steps – Normal Sequence

Scenario Name :		***PS1: Aggregator provides CRP bids to Flexibility Market***				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1a	Forecast update Periodically	Service Provider sends price forecasts to AMS.DA	SP	AMS.DA	Price forecast	TT1, TR4, SA4, A0
1b	Flexibility report Periodically	MGMS.DT sends periodically a report of the flexibility to AMS.DA	MGMS.DT	AMS.DA	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s])	TT1, TR4, SA4, A0
2	Data aggregation	AMS.DA sends all received flexibility reports to AMS.DM for data management	AMS.DA	AMS.DM	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s])	TT1, TR4, SA2, A0
3	Data management	AMS.DM aggregates information from all flexible resources that it has for the next time period and sends that data to Trading System for bid creation	AMS.DM	AMS.TS	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s])	TT1, TR4, SA2, A0
4	Bid creation	AMS.TS creates flexibility bids for the markets	AMS.TS	AMS.TS	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA2, A0
5	Bids are created and ready to be send for the markets	AMS.TS sends the bids to AMS.DM to be sent to markets	AMS.TS	AMS.DM	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA2, A0
6	Bids are created and ready to be send for the markets	AMS.DM sends the bids to AMS.DT to be sent to markets	AMS.DM	AMS.DT	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA2, A0
7	Bid(s) is ready to be sent to FMP	AMS.DT sends the offer to FMP.DA	AMS.DT	FMP.DA	Time series of available up and down flexibility for every cycle step (Location, Power [kW], Direction (up/down), Duration time [s], Activation time [s],**Price [€/MW]**)	TT1, TR4, SA4, A0
8	Confirmation	FMP confirms that the bid(s) is	FMP.DA	AMS.DT	FMP informs AMS about	TT1, TR4,

	notice	received in the market place			received bids	SA4, A0

Scenario Name :		*PS2: Aggregator's bid(s) gets accepted in FMP*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Require-ments ID***
1	Bid is accepted	FMP sends notification to AMS that the bid is accepted as a reserve for CRP	FMP.DT	AMS.DA	Notification of accepted bid (ID, time, price)	TT1, TR4, SA4, A0
2	Notification is received	AMS.DA sends the notification to Data Management	AMS.DA	AMS.DM	Notification of accepted bid (ID, time, price)	TT1, TR4, SA2, A0
3	Notification is sent to Data Management	Data Management separetes the DERs of different microgrids from the bid to be sent to corresponding MOs.	AMS.DM	AMS.DT	Notification of accepted bid (ID, time, price)	TT1, TR4, SA2, A0
4	Reports to different microgrids is created	AMS.DT sends reports to those microgrids that were included in the bid that got accepted	AMS.DT	MGMS.DA	Notification of accepted bid (ID, time, price)	TT1, TR4, SA4, A0

Scenario Name :		*PS3: Aggregator's bid(s) gets activated by DSO*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1	Bid is activated	DSO sends notification to AMS that the bid that was accepted to a reserve now needs to be activated	DMS.DT	AMS.DA	Notification of activated bid (ID, time, price)	TT3, TR4, SA4, A2
2	Notification is received	AMS.DA sends the notification to Data Management	AMS.DA	AMS.DM	Notification of activated bid (ID, time, price)	TT3, TR4, SA2, A2
3	Notification is sent to Data Management	Data Management separetes the DERs of different microgrids from the bid to be sent to corresponding MOs.	AMS.DM	AMS.DT	Notification of activated bid (ID, time, price)	TT3, TR4, SA2, A2
4	Reports to different microgrids is created	AMS.DT sends activation commands to those microgrids that were included in the bid that got activated	AMS.DT	MGMS.DA	Notification of activated bid (ID, time, price)	TT3, TR4, SA4, A2
5	Regulation is executed inside microgrids	MO sends report of activated (executed) regulations	MGMS.DT	AMS.DA	Report/time-series	TT1, TR4, SA4, A0
6	Report of executed regulation from (several) microgrid is received	AMS.DA sends the report to Data Management for report aggregation	AMS.DA	AMS.DM	Report/time-series	TT1, TR4, SA2, A0
7	Reports are aggregated in Data Management	Data Management aggregates reports from (possibly) several microgrids and creates one report corresponding the initial bid. Then sends it to Data Transmission	AMS.DM	AMS.DT	Report/time-series	TT1, TR4, SA2, A0
8	Report is ready to be sent to DMS	AMS.DT sends the report of activated regulations to DMS.DA	AMS.DT	DMS.DA	Report/time-series	TT1, TR4, SA4, A0

DSO flexibility (DSO) detailed

1 Description of the Use Case

Name of Use Case

Flexibility management of Microgrids by DSO (FMM)

Version Management

Changes / Version	*Date*	*Name Author(s) or Committee*	**Domain Expert** Primary, additional	*Area of Expertise / Domain / Role*	*Title*	*Approval Status* draft, for comments, for voting, final
Version 0.1: Technical part of the use case	17.11.2017	Author: Aleksei Mashlakov (LUT) Reviewers: Ville Tikka Samuli Honkapuro	Primary	Energy experts, core team	First draft	Draft for comments
Version 0.2: (adjusted terminology)	04.01.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Second draft	Draft for review
Version 0.3: (harmonizing detailed use cases with implementation use case)	22.03.2018	Aleksei Mashlakov (LUT)	Primary	Core team	Final	Final

Basic Information to Use Case

Source(s) / Literature	*Link*	*Conditions (limitations) of Use*

Relation to Higher Level Use Case	
Cluster	***Higher Level Use Case***
Control	Flexibility management

Maturity of Use Case
Under development
Prioritization
High
Generic, Regional or National Relation

Generic
View *- Technical / Business*
Technical
Further Keywords for Classification
Power quality control, flexibility management, microgrid control

Scope and Objectives of Use Case

Scope of Function
This use case demonstrates how Distribution System Operator (DSO) interacts with both Flexibility Market Operator (FMO) in order to evaluate the feasibility of applications of flexible resources and Aggregator to activate flexibility of microgrids if necessary.
Objectives of Function
This is needed by DSO to improve power quality in the network and optimize expenses in the conditions of grid fragmentation and high DER adoption.

Narrative of Use Case

Short description *– max 3 sentences*

This use case demonstrates how DSO interacts with FMO and Aggregator to improve power quality in the network by use of flexibility potential of microgrids as conditional re-profiling (CRP) product.

Complete description

Microgrid flexibility as a flexibility market commodity could reach and balance the following goals of DSO for scenarios of high DER adoption:

- Mitigation of congestions in the LV/MV networks
- Handling ramping issues
- Reduction of the LV/MV network losses
- Minimizing the load control actions and tap changer operations
- Reducing the voltage violation at each node
- Maintain frequency stability within the temporary island operation of distribution grid

This use case provides the required interfaces for operation of the DSO flexibility management.

DSO is represented by the automation system called Distribution Management System (DMS) that can directly interact with the following actors:

- Aggregator Management System (AMS) that distributes capacity control commands of DMS to microgrids whose flexibility was purchased in advance.
- Flexibility Market Platform (FMP) that provides aggregated flexibility potential information of microgrids and price bids for activation of this capacity.

The use case can be divided on cycle ahead and real-time actions that include following parts:

- **Purchase of CRP product:** On the cycle-ahead part DMS provides ***state forecast*** of the grid and defines possible power quality violation. To prevent deterioration of the power quality, DMS ***requests list of flexibility offers*** from FMP that corresponds to DMS control area, then DMS calculates ***state optimization***, and purchases CRP products by ***requesting bids*** from FMP.
- **Activation of purchased CRP:** On the real-time part, DMS uses ***state estimation of the grid*** and, if the quality deterioration is detected, it defines optimal real-time set points (***state optimization***) for microgrid flexibility and sends ***activation commands*** to microgrids through AMS.
- **Verification phase:** Finally, the DMS is receiving verification reports allowing to verify the implementation of sent

commands and provide compensation for the service. * Verification of resource activation and monitoring of flexibility offers by DMS are not described in this use case since it is defined in DSO monitoring use case.

Actors: Detailed Terminology

Actor Name	*Actor Type*	*Actor Description*	*Further information specific to this Use Case*
AMS	System	Aggregator Management System	
AMS.DA	Function	Aggregator Management System Data Acquisition	
FMP	System	Flexibility Market Platform	
FMP.DT	Function	Flexibility Market Platform Data Transmission	
DMS	System	Distribution Management System	
DMS.DT	Function	Distribution Management System Data Transmission	
DMS.DA	Function	Distribution Management System Data Acquisition	
DMS.DM	Function	Distribution Management System Data Management	
DMS.SO	Function	Distribution Management System State Optimization	
DMS.SF	Function	Distribution Management System State Forecast	
DMS.SE	Function	Distribution Management System State Estimation	

Issues: Legal Contracts, Legal Regulations, Constraints and others

Issue - here specific ones	*Impact of Issue on Use Case*	**Reference** – *law, standard, others*

Preconditions, Assumptions, Post condition, Events

Actor/System/Information/Contract	*Triggering Event*	*Pre-conditions*	*Assumption*	**Post-conditions**
AMS		The system is up and running.		
DMS		The system is up and running.		
FMP		The system is up and running.		

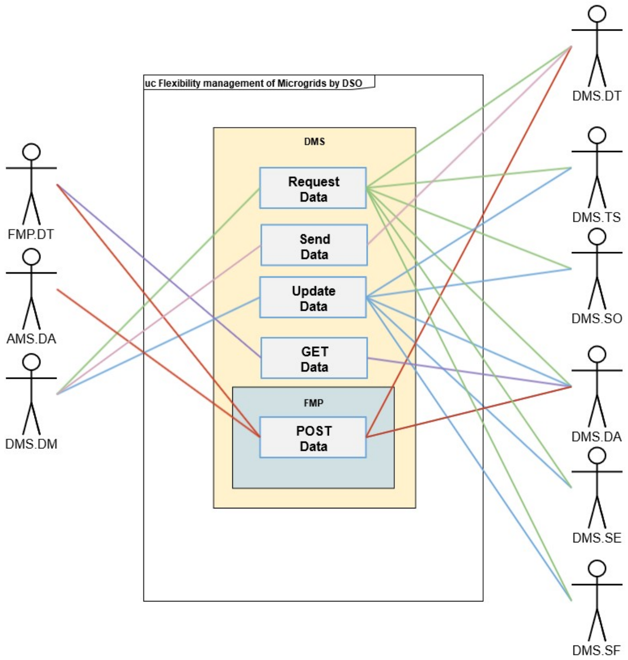
Referenced Standards and / or Standardization Committees (if available)

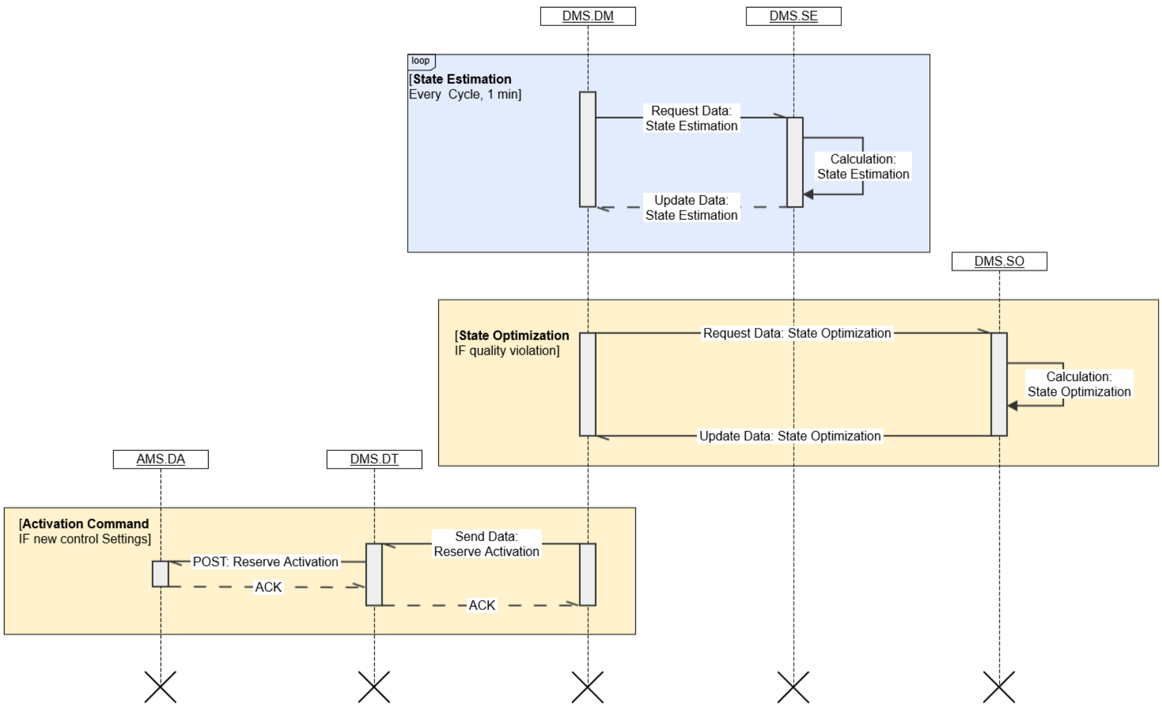
Relevant Standardization Committees	*Standards supporting the Use Case*	*Standard Status*

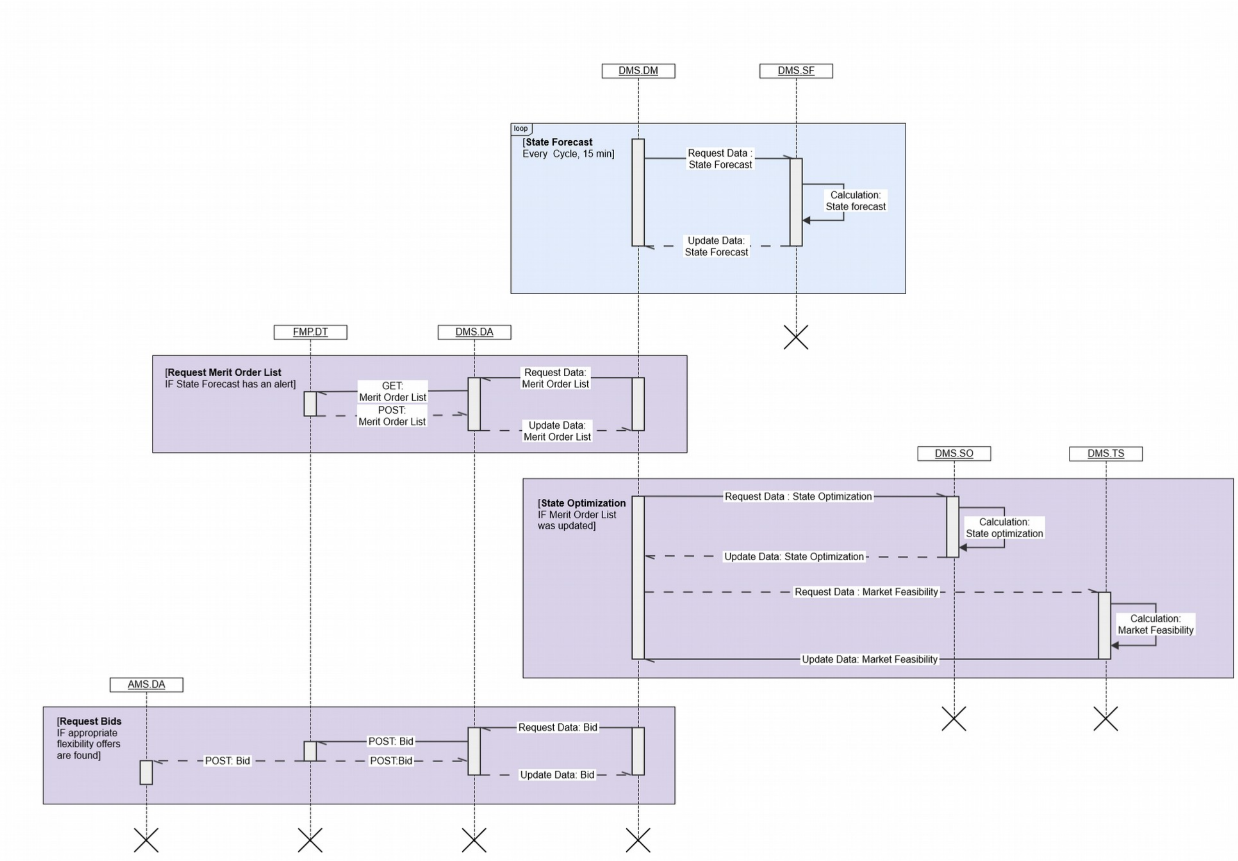
General Remarks

General Remarks

2 Drawing or Diagram of Use Case







3 Step by Step Analysis of Use Case

Scenatio No.	Primary Actor	Triggering Event	Pre-Condition	Post-Condition
PS1: DMS purchases CRP product	DMS.SF	Violation of power quality was forecasted by DMS.SF.	There are available CRP products (microgrid flexibility) in the flexibility market that could be used by DMS to improve power quality.	The CRP product was purchased by DMS. The contract between AMS and DMS was approved.
PS2: DMS activates resources of microgrids	DMS.SE	Violation of power quality was detected by DMS.SE	DMS has received the measurements from the grid sensors that are necessary for state estimation.	Control commands are being implemented by microgrids.
AS1: State Optimization Calculation does not converge	DMS.SO	State optimization is not converged.	Data for optimal power flow analysis are retrieved.	DMS utilizes other resources to improve power quality.
AS2: The available resources are not adequate to restore the network to an acceptable state	DMS.SO	State optimization is done.	All data of microgrids flexibility are delivered to DMS.SO	None control commands sent to AMS.
AS3: Proper input data are not available	DMS.SO	Data error.	All data of microgrids flexibility are delivered to DMS.SO.	DMS.SO is not calculated.
AS4: Offers rejected	DMS.TS	Economic analysis is done.	Data for economic analysis are retrieved.	No control commands is sent to FMP.
AS5: Resource activation was incomplete	DMS.TS	Verification of resource activation	DMS requests validation of resources.	Re-calculations are needed by DMS.TS.

		was acquired.		

Steps – Normal Sequence

Scenario Name :	PS1: DMS purchases CRP product					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1	Request Data: State Forecast	DMS.DM requests state forecast report from DMS.SF	DMS.DM	DMS.SF	Request signal [state forecast]	TT1 TR4 SA2 A0
2	Calculations: State Forecast	DMS.SF calculates the expected state of the grid	DMS.SF	DMS.SF	No information exchange	TT1 TR4 SA2 A0
3	Update Data: State Forecast	DMS.SF forecasts violation of power quality and sends the alert report to DMS.DM	DMS.SF	DMS.DM	Report [state forecast]	TT1 TR4 SA2 A0
4	Request Data: Merit Order List	DMS.DM requests offers list from DMS.DA	DMS.DM	DMS.DA	Request signal [offers list]	TT1 TR4 SA2 A0
5	GET: Merit Order List	DMS.DA requests offers list from FMP.DT	DMS.DA	FMP.DT	Request signal [offers list]	TT1 TR4 SA4 A0
6	POST: Merit Order List	FMT.DT returns requested offers list	FMP.DT	DMS.DA	Report [offers list]	TT1 TR4 SA4 A0
7	Update Data: Merit Order List	DMS.DA returns requested offers list to DMS.DM	DMS.DA	DMS.DM	Report [offers list]	TT1 TR4 SA2 A0
8	Request Data: State Optimization	DMS.DM requests state optimization report from DMS.SO	DMS.DM	DMS.SO	Request signal [state optimization] Report [offers list] Report [state forecast]	TT1 TR4 SA2 A0
9	Calculations: State Optimization	DMS.SO provides internal calculations and checks technical feasibility of different reports, defines plans of possible control actions for each Microgrid	DMS.SO	DMS.SO	No information exchange	TT1 TR4 SA2 A0
10	Update Data: State Optimization	DMS.SO sends the outputs of calculations to DMS.DM	DMS.SO	DMS.DM	Report [state optimization]	TT1 TR4 SA2 A0
11	Request Data: Market Feasibility	DMS.DM imports the output data of DMS.SO and market offers of corresponding microgrids to DMS.TS	DMS.DM	DMS.TS	Request signal [market feasibility] Report [state optimization] Report [offers list]	TT1 TR4 SA2 A0
12	Calculations: Market Feasibility	DMS.TS accepts offers based on the economic feasibility	DMS.TS	DMS.TS	No information exchange	TT1 TR4 SA2 A0
13	Update Data: Market	DMS.TS sends the outputs of TS	DMS.TS	DMS.DM	Report [market	TT1 TR4 SA2

	Feasibility	calculations to DMS.DM			feasibility]	A0
14	Request Data: Bid	DMS.DM requests the approval of bids from DMS.DA	DMS.DM	DMS.DA	Request signal [bid] Report [market feasibility]	TT1 TR4 SA2 A0
15	POST: Bid	DMS.DA requests the approval of bids from FMP.DT	DMS.DA	FMP.DT	Request signal [bid] Report [market feasibility]	TT1 TR4 SA4 A0
16	POST: Bid	FMP.DT sends confirms of flexibility offers	FMP.DT	DMS.DA AMS.DA	Report [bid]	TT1 TR4 SA4 A0
17	Update Data: Bid	DMS.DA redirects confirms of flexibility offers to DMS.DM	DMS.DA	DMS.DM	Report [bid]	TT1 TR4 SA2 A0

Scenario Name :	PS2: DMS activates resources of Microgrids					
Step No.	***Name of Process/ Activity***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
1	Request Data: State Estimation	DMS.DM requests state estimation report from DMS.SE	DMS.DM	DMS.SE	Request signal [state forecast] Report [real-time grid measurements]	TT3 TR4 SA2 A2
2	Calculations: State Estimation	DMS.SE calculates the current state of the grid	DMS.SE	DMS.SE	No information exchange	
3	Update Data: State Estimation	DMS.SE detects violation of power quality and sends the alert report to DMS.DM	DMS.SE	DMS.DM	Report [state estimation]	TT3 TR4 SA2 A2
4	Request Data: State Optimization	DMS.DM requests state optimization report	DMS.DM	DMS.SO	Request signal [state optimization] Report [state forecast]	TT3 TR4 SA2 A2
5	Calculations: State Optimization	DMS.SO provides internal calculations and defines plans of possible control actions for each microgrid	DMS.SO	DMS.SO	No information exchange	
6	Update Data: State Optimization	DMS.SO sends the outputs of SO calculations to DMS.DM	DMS.SO	DMS.DM	Report [state optimization]	TT3 TR4 SA2 A2
7	Send Data: Reserve Activation	DMS.DM imports the output data of DMS.SO to DMS.DT	DMS.DM	DMS.DT	Request signal [activation command] Report [state optimization]	TT3 TR4 SA2 A2
8	POST Data: Reserve Activation	DMS.DT sends the control commands to AMS.DA	DMS.DT	AMS.DA	Request signal [activation command] Report [state optimization]	TT3 TR4 SA4 A2

Steps – Alternative, Error Management, and/or Maintenance/Backup Scenario

Scenario Name :	*AS1: SO does not converge*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
9a1	Calculations: State Optimization (does not converge)	Recovery methods are tried. These can include e.g. changing the optimization algorithm parameters such as the number of iteration rounds, type of limits etc.	DMS.SO	DMS.SO	No information exchange	
9a2	Calculations: State Optimization (converges with recovery methods)	Return to step 7: DMS.SO sends the outputs of SO calculations to DMS.DM	DMS.SO	DMS.DM	Report [state optimization]	
9a3	Calculations: State Optimization (does not converge with recovery methods)	Stop DMS.SO operation and wait for the next measurements to come in. Write a log message stating the problem with SO to DMS.DM.	DMS.SO	DMS.DM	Alert signal [state optimization]	

Scenario Name :	*AS2: The available resources are not adequate to restore the network to an acceptable state*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
9b1	Calculations: State Optimization (available controllable resources of microgrids are not adequate to restore the network to an acceptable state)	Stop DMS.SO operation and wait for the next measurements to come in. Write a log message stating the problem with SO to DMS.DM.	DMS.SO	DMS.DM	Alert report [state optimization]	

Scenario Name :	*AS3: Proper input data are not available*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
9c1	Calculations: State Optimization (input data are not available or not valid)	SO calculation is not started and the next measurements are waited for. A log message is written to DMS.DM.	DMS.SO	DMS.DM	Alert report [state optimization]	

Scenario Name :	*AS4: Offers are rejects*					
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
9d1	Calculations: Market Feasibility (offers economically inadequate)	Stop DMS.TS operation and wait for the next offers to come in. Write a log message to DMS.DM.	DMS.TS	DMS.DM	Report [market feasibility]	

Scenario Name :		*AS5: Resource activation was incomplete*				
Step No.	***Event***	***Description of Process/Activity***	***Information Producer***	***Information Receiver***	***Information Exchanged***	***Technical Requirements ID***
9e1	Calculations: Market Feasibility (activation was incomplete.)	DMS.DM imports the data to DMS.TS to make re-calculations of rewards.	DMS.TS	DMS.TS	No information exchanged	

Appendix III – Implementation Use Cases

Contents

Frequency Containment Reserve (FCR) implementation use case

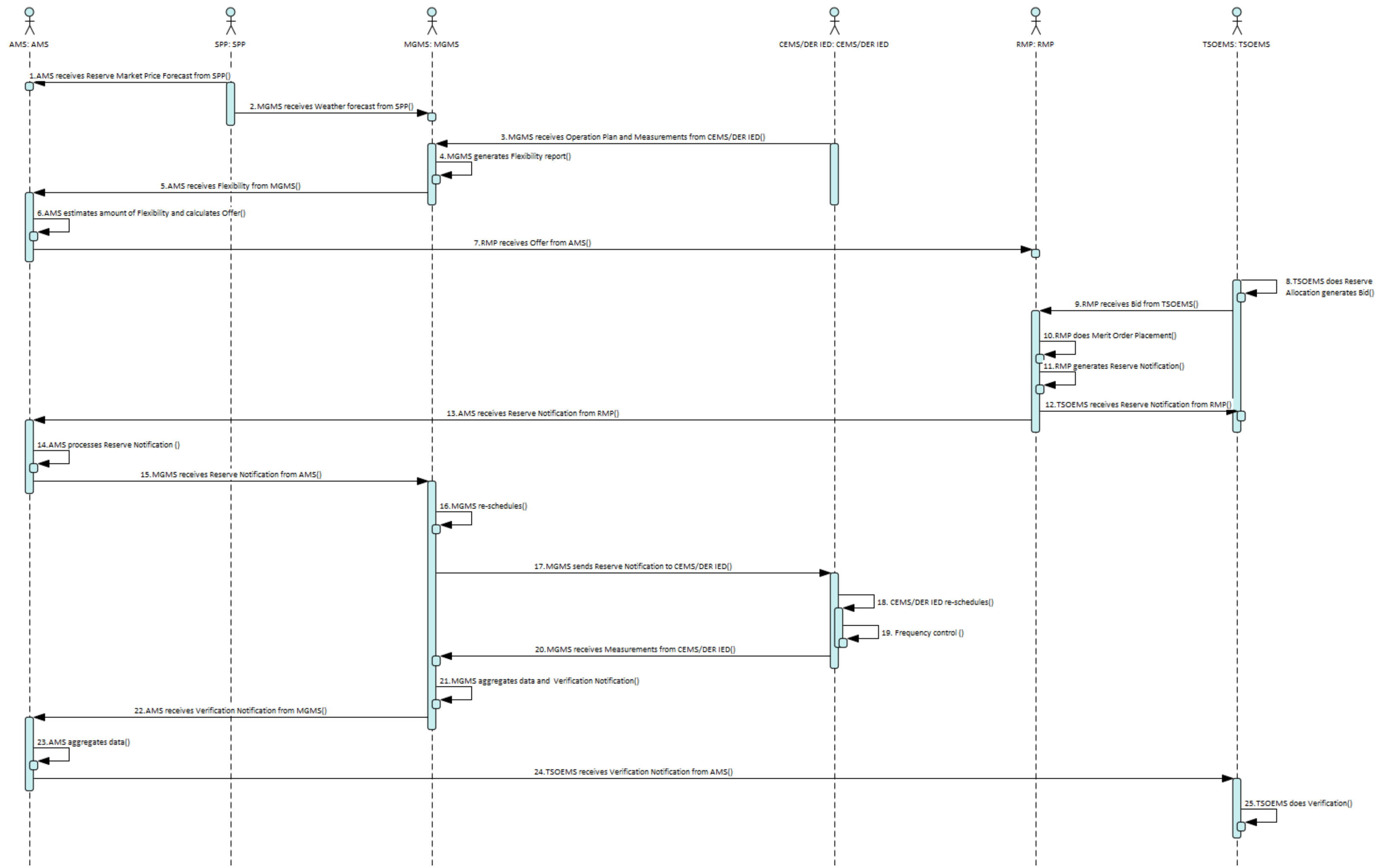


Figure III.1. Sequence diagram of FCR implementation use case

Table III.1. Steps of FCR use case sequence diagrams.

Step	FCR
1	AMS receives Reserve Market Price Forecast from SPP (Market Service Provider)
2	MGMS receives Weather Forecast from SPP (Weather Service Provider)
3	MGMS receives Operation Plan and/or Measurements from CEMS/DER IED
4	MGMS generates Flexibility report
5	AMS receives Flexibility from MGMS
6	AMS estimates amount of Flexibility and calculates Offer
7	RMP receives Offer from AMS
8	TSO EMS does Reserve Allocation and generates Bid
9	RMP receives Bid from TSO EMS
10	RMP does Merit Order Placement
11	RMP generates Reserve Notification as a result of market clearance
12	TSO EMS receives Reserve Notification from RMP
13	AMS receives Reserve Notification from RMP
14	AMS processes the Reserve Notification
15	MGMS receives Reserve Notification from AMS
16	MGMS processes the Reserve Notification and re-schedules
17	MGMS sends Reserve Notification to CEMS/DER IED
18	CEMS/DER IED re-schedules
19	CEMS/DER IED operates in frequency control mode
20	MGMS receives Verification Notification and/or Measurements from CEMS/DER IED
21	MGMS aggregates the data and creates Verification Notification

22	AMS receives Verification Notification from MGMS
23	AMS aggregates the data and creates Verification Notification
24	TSO EMS receives Verification Notification from AMS
25	TSO EMS conducts Reserve Verification

Table III.2. Messages between actors. Information objects for the SGAM and message types from SmartAPI for message handling/processing. Steps refer to Table III.1. Coloring: White=HEILA messages, blue=legacy equipment and yellow=HEILA or legacy.

Use case name	Step number	Function name	Information producer	Information receiver	Information description	Information object (in SGAM)	SmartAPI NS entity type + references in ValueObjects	Protocol	Technology	Transfer time	Transfer rate	Synchro-nization accuracy	Availability
FCR	1		SPP (Market Service Provider)	AMS	**Reserve Price Forecast** – forecasted prices on the day-ahead FCR-N market that are used by aggregator to make suitable offers to the market.	Reserve Market Price Forecast	In case of Smart API Reserve Price Forecast Service: **TimeSeries** {IdentifierUri = {server}/ReservePriceForecast Type: {namespace}**ReservePriceForecast** **List** [20, 23, …, 25, 20.1] **baseObject** [1. unit=(e.g. Euro), quantity=(e.g. Price)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-05-29T12:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-05-29T13:00:00.000)] **timeStep** [dataType=duration, (e.g. 01:00:00)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
FCR	2		SPP (Weather Service Provider)	MGMS	**Weather forecast** – day-ahead weather characteristics (radiation, cloudiness, temperature, etc.) required to forecast flexibility.	Weather Forecast	In case of Weather Forecast Service API: **TimeSeries** {IdentifierUri = {server}/WeatherForecast/ Type: {namespace}**WeatherForecast**	lab-dependent	ICT connection	TT0	TR4	SA4	A0

							List [20.3, 24.5, …, 18.3, 17.4] **baseObject** [1. unit=(e.g. Celcius), quantity=(e.g. Temperature)] **temporalContext** [1. start dataType=dateTime, value=(e.g.2018-05-29T12:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-05-29T12:30:00.000)] **timeStep** [dataType=duration, (e.g. 00:05:00)]}						
FCR	3		DER IED/CEMS	MGMS	**Operation Plan** - hourly schedule of DER for the next day (baseline load/generation).	Operation Plan	In case of Smart API: **TimeSeries** {IdentifierUri = {server}/OperationPlan/{slot} Type: {namespace}**OperationPlan** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] **timeStep** [dataType=duration, (e.g. 00:01:00)]}	lab-dependent	ICT connection	TT0	TR4	SA4	A0
FCR	3		MG IED	MGMS	Current measurement [A]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	3		MG IED	MGMS	Voltage measurement [V]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0

FCR	3		MG IED	MGMS	Apparent power [VA]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	3		MG IED	MGMS	Active power [W]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	3		MG IED	MGMS	Reactive power [Var]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	3		MG IED	MGMS	Power Factor	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	3		MG IED	MGMS	Circuit breaker state [On/Off]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	5		MGMS	AMS	**Flexibility** – forecast of day-ahead hourly flexibility of microgrid customers/prosumers aggregated at the microgrid point of common coupling. [1. Offer ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time]	Flexibility	**Entity** {IdentifierUri = {server}/Flexibility/{entityname}/{slot} Type: {namespace}**Flexibility** Entity value objects: 1. dataType=string, value= (e.g. 123) 2. dataType=string, value=(e.g. FCR-N) 3. unit=(Watt), quantity=ActivePower, value=(e.g. 5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
FCR	7		AMS	RMP	**Offer** - hourly bid of the aggregator to the day-ahead FCR-N market. [1. Offer ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time	Offer	**Entity** {IdentifierURI = {server}/Offer/{slot} Type: {namespace}**Offer** Entity value objects: 1. dataType=string, value= (e.g. 10) 2. dataType=string, value=(e.g. FCR-N) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-	HTTPS	ICT connection	TT0	TR4	SA4	A0

					6. Price]		17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T06:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}						
FCR	9		TSO EMS	RMP	**Bid** - hourly FCR-N capacity required by TSO for the next day. [1. Bid ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time 6. Price]	Bid	**Entity** {IdentifierURI = {server}/Bid/{slot} Type: {namespace}**Bid** Entity value objects: 1. dataType=string, value= (e.g. 10) 2. dataType=string, value=(e.g. FCR-N) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T06:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
FCR	12		RMP	TSO EMS	**Reserve Notification** - acquired hourly FCR-N capacity for the next day. [1. Bid ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time 6. Price]	Reserve Notification	**Entity** {IdentifierURI = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** Entity value objects: 1. dataType=string, value= (e.g. 10) 2. dataType=string, value=(e.g. FCR-N) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000)] 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T06:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0

FCR	13		RMP	AMS	**Reserve Notification -** approved hourly Offers of the aggregator for the FCR-N service. [1. Offer ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time 6. Price]	Reserve Notification	**Entity** {IdentifierURI = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** Entity value objects: 1. dataType=string, value= (e.g. 10) 2. dataType=string, value=(e.g. FCR-N) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T06:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)}	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0
FCR	15		AMS	MGMS	**Reserve Notification -** hourly microgrid capacity scheduled for the provision of FCR-N service for the next day. [1. Flexibility ID 2. Flexibility type 3. Active Power 4. Start time 5. Stop time]	Reserve Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** Entity value objects: 1. dataType=string, value=(e.g. 123) 2. dataType=string, value=(e.g. FCR-N) 3. unit=(Watt), quantity=ActivePower, value=(e.g. 5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T06:00:00.000)]}	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0
FCR	17		MGMS	DER	**Reserve Notification -** hourly DER capacity scheduled for the FCR-N service of the next day.	Reserve Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** 1. dataType=string, value= (e.g 123)	lab-dependent	ICT connection	TT0	TR4	SA3	A0

							2. dataType=string, value=(e.g. FCR-N) 3. unit=Watt, quantity=ActivePower, value=(e.g.5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}						
FCR	20		DER	MGMS	**Verification Notification** - information about the measured DER capacity maintained/activated for FCR-N.	Verification Notification	In case of Smart API: **TimeSeries** {IdentifierUri = {server}/ VerificationNotification/{requesting_entity}/{slot} Type: {namespace}**VerificationNotification** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] **timeStep** [dataType=duration, (e.g. 00:00:01)]}	lab-dependent	ICT connection	TT0	TR4	SA3	A0
FCR	20		MG IED	MGMS	Current measurement [A]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	20		MG IED	MGMS	Voltage measurement [V]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	20		MG IED	MGMS	Apparent power [VA]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	20		MG IED	MGMS	Active power [W]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0

FCR	20		MG IED	MGMS	Reactive power [Var]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	20		MG IED	MGMS	Power Factor	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	20		MG IED	MGMS	Circuit breaker state [On/Off]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA3	A0
FCR	22		MGMS	AMS	**Verification Notification -** information about the measured microgrid capacity maintained/ activated for FCR-N.	Verification Notification	**TimeSeries** {IdentifierUri = {server}/ VerificationNotification/ {requesting_entity}/{slot} Type: {namespace}**VerificationNotification** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] **timeStep** [dataType=duration, (e.g. 00:00:01)] }	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0
FCR	24		AMS	TSO EMS	**Verification Notification -** information about the measured aggregator Offer capacity maintained/ activated for FCR-N.	Verification Notification	**TimeSeries** {IdentifierUri = {server}/ VerificationNotification/{requesting_entity}/{slot} Type: {namespace}**VerificationNotification** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-	HTTPS	ICT connection	TT0	TR4	SA4	A0

							17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] **timeStep** [dataType=duration, (e.g. 00:00:01)] }						

DSO Flexibility implementation use case

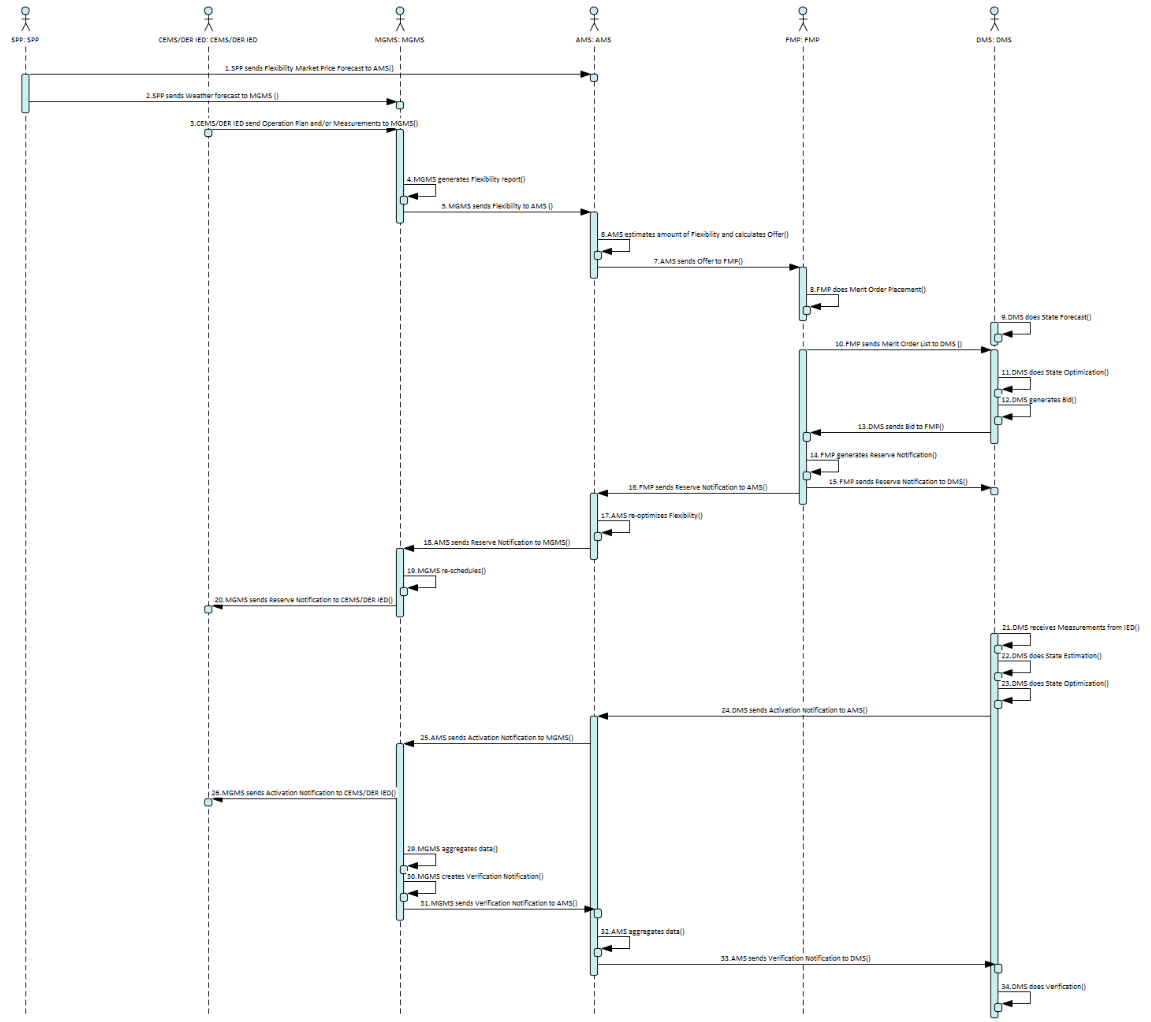


Figure III.2. Sequence diagram of DSO Flexibility use case

Table III.3. Steps of DSO Flexibility use case sequence diagrams.

Step	DSO Flexibility
1	AMS receives Flexibility Market Price Forecast from SPP (Market Service Provider)
2	MGMS receives Weather forecast from SPP (Weather Service Provider)
3	MGMS receives Operation Plan and/or Measurements from CEMS/DER IED
4	MGMS generates Flexibility report
5	AMS receives Flexibility from MGMS
6	AMS estimates amount of Flexibility and calculates Offer
7	FMP receives Offer from AMS
8	FMP does Offer Ranking
9	DMS does State Forecast
10	DMS receives Offer List from FMP
11	DMS does State Optimization
12	DMS generates Bid
13	FMP receives Bid from DMS
14	FMP generates Reserve Notification
15	DMS receives Reserve Notification from FMP
16	AMS receives Reserve Notification from FMP
17	AMS re-optimizes Flexibility
18	MGMS receives Reserve Notification from AMS
19	MGMS re-schedules
20	MGMS sends Reserve Notification to CEMS/DER IED
21	DMS receives Measurements from IED

22	DMS does State Estimation
23	DMS does State Optimization
24	AMS receives Activation Notification from DMS
25	MGMS receives Activation Notification from AMS
26	MGMS sends Activation Notification to CEMS/DER IED
27	CEMS/DER IED controls the process
28	MGMS receives Measurements from CEMS/DER IED
29	MGMS aggregates data
30	MGMS creates Verification Notification
31	AMS receives Verification Notification from MGMS
32	AMS aggregates data
33	DMS receives Verification Notification from AMS
34	DMS does Verification

Table III.4. Messages between actors. Information objects for the SGAM and message types from SmartAPI for message handling/processing. Steps refer to Table III.3. Coloring: White=HEILA messages, blue=legacy equipment and yellow=HEILA or legacy.

Use case name	Step number	Function name	Information producer	Information receiver	Information description	Information object (in SGAM)	SmartAPI NS references	Protocol	Technology	Transfer time	Transfer rate	Synchro-nization accuracy	Availability
DSO flexi-bility	1		SPP	AMS	**Flexibility market price forecast** – Timeseries of forecasted prices with cycle step for the next hour.	Flexibility Price Forecast	In case of SmartAPI: **TimeSeries** {IdentifierUri = {server}/ FlexibilityPriceForecast Type: {namespace}**FlexibilityPriceForecast** **List** [20.5, 21.4, …, 45.5, 23.0] **baseObject** [1. unit=(e.g.Euro), quantity=(e.g. Price)]	HTTPS	ICT connection	TT0	TR4	SA4	A0

							temporalContext [1. start dataType=dateTime,value=(e.g.2018-05-29T12:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-05-29T13:00:00.000)] **timeStep** [dataType=duration, (e.g. 15)]}						
DSO flexi-bility	2		SPP	MGMS	**Weather forecast** – Time-series of forecasted weather data (radiation, aver. temperature, aver. wind speed) as a function of coordinates with cycle step for the next hour.	Weather Forecast	In case of Weather Forecast Service API: **TimeSeries** {IdentifierUri = {server}/WeatherForecast/ Type: {namespace}**WeatherForecast** **List** [20.3, 24.5, …, 18.3, 17.4] **baseObject** [1. unit=(e.g. Celcius), quantity=(e.g. Temperature)] **temporalContext** [1. start dataType=dateTime, value=(e.g.2018-05-29T12:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-05-29T12:30:00.000)] **timeStep** [dataType=duration, (e.g. 00:05:00)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-bility	3		MG IED	MGMS	Current measurement [A]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO flexi-bility	3		MG IED	MGMS	Voltage measurement [V]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO	3		MG IED	MGMS	Apparent power [VA]	Measurements		lab-	ICT	TT1	TR4	SA4	A0

flexi-bility								dependent	connection				
DSO flexi-bility	3		MG IED	MGMS	Active power [W]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO flexi-bility	3		MG IED	MGMS	Reactive power [Var]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO flexi-bility	3		MG IED	MGMS	Power Factor	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO flexi-bility	3		MG IED	MGMS	Circuit breaker state [On/Off]	Measurements		lab-dependent	ICT connection	TT1	TR4	SA4	A0
DSO flexi-bility	3		DER IED/CEMS	MGMS	**Operation Plan** – Baseline load/generation schedule.	Operation Plan	In case of Smart API: **TimeSeries** {IdentifierUri = {server}/OperationPlan/{slot} Type: {namespace}**OperationPlan** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] **timeStep** [dataType=duration, (e.g. 00:01:00)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-	5		MGMS	AMS	**Flexibility** – Location dependent packages of	Flexibility	**Entity** {IdentifierUri =	HTTPS	ICT	TT0	TR4	SA4	A0

bility					forecasted up- and down-regulation for the next cycle step: [1. Flexibility ID 2. Flexibility type [CRP, SRP] 3. PQ profile (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time]		{server}/Flexibility/{entityname}/{slot} Type: {namespace}**Flexibility** Entity value objects: 1. dataType=string, value= (e.g 123) 2. dataType=string, value=(e.g.CRP) 3. unit=(e.g.Watt), quantity=ActivePower, value=(e.g.5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}		connection				
DSO flexi-bility	7		AMS	FMP	**Offer** – Location dependent packages of up- and down-regulation offered by aggregator for the next cycle step: [1. Offer ID 2. Flexibility type [CRP, SRP] 3. PQ profile (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time 6. Price [€]]	Offer	**Entity** {IdentifierURI = {server}/Offer/{slot} Type: {namespace}**Offer** Entity value objects: 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-bility	10		FMP	DMS	**Offer list** – Location and price dependent packages of up- and down-regulation received by FMP for the next cycle step: [1. Offer ID 2. Flexibility type [CRP, SRP]	Offer List	**Entity** {IdentifierURI = {server}/OfferList/{slot} Type: {namespace}**OfferList** Entity value objects: 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP)	HTTPS	ICT connection	TT0	TR4	SA4	A0

					3. PQ profile (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time 6. Price [€]]		3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}						
DSO flexi-bility	13		DMS	FMP	**Bid** – Location dependent packages of up- and down-regulation requested by DMS: [1. Bid ID 2. Flexibility type [CRP, SRP] 3. PQ profile (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time 6. Price [€]]	Bid	**Entity** {IdentifierURI = {server}/Bid/{slot} Type: {namespace}**Bid** Entity value objects: 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}	HTTPS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-bility	15		FMP	DMS	**Reserve Notification** – Location dependent packages of up- and down-regulation reserved by FMP for DMS: [1. Bid ID 2. Flexibility type [CRP, SRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time	Reserve Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0

					5. Stop time 6. Price [€]]		04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}						
DSO flexi-bility	16		FMP	AMS	**Reserve Notification** – Location dependent packages of up- and down-regulation reserved by FMP for AMS: [1. Offer ID 2. Flexibility type [CRP, SRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time 6. Price [€]]	Reserve Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 15)]}	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-bility	18		AMS	MGMS	**Reserve Notification** – Location dependent packages of up- and down-regulation reserved by AMS for MGMS: [1. Flexibility ID 2. Flexibility type [CRP, SRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time 6. Price [€]]	Reserve Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** 1. dataType=string, value= (e.g 123) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000) 6. unit=Euro, quantity=Price, value=(e.g. 5)]}	MQTT over TLS	ICT connection	TT0	TR4	SA4	A0
DSO flexi-	20		MGMS	CEMS/	**Reserve Notification** – Location dependent	Reserve	In case of SmartAPI:	lab-	ICT	TT0	TR4	SA4	A0

bility				DER IED	packages of up- and down-regulation reserved by MGMS: [1. Plan ID 2. Flexibility type [CRP, SRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time]	Notification	**Entity** {IdentifierUri = {server}/ReserveNotification/{requesting_entity}/{slot} Type: {namespace}**ReserveNotification** 1. dataType=string, value= (e.g 123) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:00:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}	dependent e.g. MQTT over TLS	connection				
DSO flexi-bility	24		DMS	AMS	**Activation Notification** – Notification for a conditional re-profiling of reserved up- and down-regulation packages: [1. Offer ID 2. Flexibility type [CRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time]	Activation Notification	**Entity** {IdentifierUri = {server}/ ActivationNotification /{requesting_entity}/{slot} Type: {namespace}**ActivationNotification** 1. dataType=string, value= (e.g 10) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.15000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:20:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}	MQTT over TLS	ICT connection	TT3	TR4	SA4	A0
DSO flexi-bility	25		AMS	MGMS	**Activation Notification** – Notification for a conditional re-profiling of reserved up- and down-regulation packages: [1. Flexibility ID 2. Flexibility type [CRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var])	Activation Notification	**Entity** {IdentifierUri = {server}/ ActivationNotification /{requesting_entity}/{slot} Type: {namespace}**ActivationNotification** 1. dataType=string, value= (e.g 123) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.5000)	MQTT over TLS	ICT connection	TT3	TR4	SA4	A0

					4. Start time 5. Stop time]		4. dataType=dateTime, value=(e.g.2018-04-17T03:20:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}						
DSO flexi-bility	26		MGMS	CEMS/ DER IED/ IED	**Activation Notification** – Notification for a conditional re-profiling of reserved up- and down-regulation packages: [1. Plan ID 2. Flexibility type [CRP] 3. PQ power set-point (Active Power [W] or Reactive Power [Var]) 4. Start time 5. Stop time]	Activation Notification	In case of SmartAPI: **Entity** {IdentifierUri = {server}/ ActivationNotification /{requesting_entity}/{slot} Type: {namespace}**ActivationNotification** 1. dataType=string, value= (e.g 123) 2. dataType=string, value=(e.g.CRP) 3. unit=Watt, quantity=ActivePower, value=(e.g.5000) 4. dataType=dateTime, value=(e.g.2018-04-17T03:20:00.000) 5. dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]}	lab-dependent e.g. MQTT over TLS	ICT connection	TT3	TR4	SA4	A0
DSO flexi-bility	31		MGMS	AMS	**Verification Notification** – Information about the measured alteration of microgrid profile compared to the baseline schedule.	Verification Notification	**TimeSeries** {IdentifierUri = {server}/ VerificationNotification/{requesting_entity}/{slot} Type: {namespace}**VerificationNotification** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)]	MQTT over TLS	ICT connection	TT3	TR4	SA4	A0

							1. **timeStep** [dataType=duration, (e.g. 00:00:01)]}						
DSO flexi-bility	33		AMS	DMS	**Verification Notification** – information about the measured alteration of AMS profile compared to the baseline schedule.	Verification Notification	**TimeSeries** {IdentifierUri = {server}/ VerificationNotification/{requesting_entity}/ {slot} Type: {namespace}**VerificationNotification** **List** [5000, 5000, …, 5000, 5000] **baseObject** [1. unit=(e.g. Watt), quantity=(e.g. ActivePower)] **temporalContext** [1. start dataType=dateTime,value=(e.g.2018-04-17T03:00:00.000) 2. end dataType=dateTime, value=(e.g.2018-04-17T04:00:00.000)] 1. **timeStep** [dataType=duration, (e.g. 00:00:01)]}	MQTT over TLS	ICT connection	TT3	TR4	SA4	A0

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