Information Exchange Platform for Enabling Ancillary Services from Distributed Energy Resources

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***Abstract*— The operation of the electrical grid is going through a major change. In future, also small-scale distributed energy resources (DERs) need to be utilized in system operation. Increasing penetration of DERs set new challenges for the grids but also open new possibilities in grid and system operation. Smart utilization of DERs would decrease the total costs of the system but barriers for widespread DER ancillary services still exist and include, amongst others, the lack of widely accepted interoperable communication interfaces and the inadequate number of studies going beyond simulations. This paper describes the development of an information exchange platform that enables interoperable data exchange between different energy system actors enabling more efficient use of customers' and other market actors' DERs in system operation. The operation of the developed information exchange platform is demonstrated with an example use case that considers utilizing DERs for frequency control through the frequency containment reserve market.**

***Index Terms*-- Ancillary Services, Data Exchange, Distributed Energy Resource, Frequency Containment Reserve, Testing Platform**

I. Introduction

The energy system is undergoing a major transition. The energy mix in electricity production is changing towards renewable, often intermittent and distributed, energy resources, load profiles are changing and new types of controllable and uncontrollable resources such as electric vehicles and energy storages are being connected to the system. At the same time, digitalization enables new types of solutions and services.

In the future smart grid, distribution networks can no longer remain passive, but also small-scale distributed energy resources (DERs) connected to them need to be utilized in system operation, both at transmission and at distribution level. Increasing penetration of DERs set new challenges for the grids but also open new possibilities in grid and system operation. Smart utilization of DERs would decrease the total costs of the system but barriers for widespread DER ancillary services still exist and include, amongst others, the lack of widely accepted interoperable communication interfaces and the inadequate number of studies going beyond simulations. There is a need for testing platforms enabling development, testing, piloting, and finally also commercialization of new smart grid functionalities.

This paper describes the development of an information exchange platform that enables interoperable data exchange between different energy system actors enabling more efficient use of customers' and other market actors' DERs in system operation. At the first stage, the platform is used as a testing platform for research purposes, but the basic principles are defined such that business use of the platform will also be possible. The implemented testing platform consists of geographically distant laboratories and enables advanced and flexible testing of future smart grid functionalities that can be quite complex and cannot be properly studied in a single laboratory or demonstration site. The test case selected as an example for this paper considers utilizing DERs for frequency control through the frequency containment reserve (FCR) market.

II. Decentralized Information Exchange Architecture

When DERs start to contribute to transmission and distribution system operation, the number of resources that are managed in real-time increases drastically. At the same time, new actors such as aggregators and new market places such as local flexibility market are emerging. This means that millions of active resources on equipment, customer and microgrid level need to be on-line reachable by several market actors as depicted in Fig. 1. It is self-evident that the currently used technical solutions that have been developed for a system where only a relatively low number of large resources participate to system operation will not be able to cope in the new operational environment where the need for information exchange is growing exponentially and the system operational principles are drastically changed.

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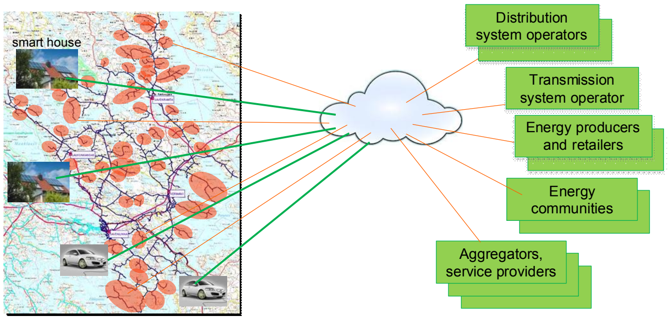

Figure 1. Distributed customer driven renewable based energy systems together with centralised market actor driven systems.

A. Decentralized architecture concept

The proposed information exchange architecture is decentralized and aims to enable efficient real-time data exchange between all energy market actors (including DER owners). Decentralized architecture decomposes the global monitoring and control tasks to partial or/and local tasks and there is no single point where all decisions are made as visualized in Fig. 2. 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.

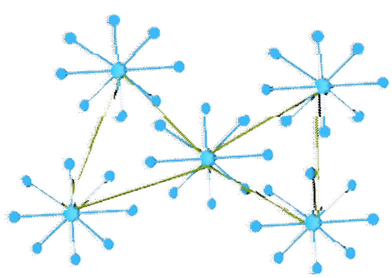

Figure 2. Basic idea of decentralized architecture. In the figure, node is a point where decisions are made and lines between nodes represent communication links that are needed to coordinate decisions.

The proposed decentralized information exchange architecture enables closer to real-time operation and, therefore, DERs can be utilized also for control actions which would not be possible in a centralized system when millions of DERs are taken as a part of system operation. The decentralized architecture is also more easily scalable than centralized architecture and there is no single point of failure. Also, the amount of communication traffic decreases since data is filtered at each node and only relevant data is sent between actors. For efficient operation, it is essential to consider data modelling so that actors can connect to the system easily and without a need to build numerous point-to-point connections with different actors that utilize different data models since this kind of system would be laborious to set up and difficult to maintain. The concept of the proposed decentralized information exchange architecture in business use is represented in Fig. 3.

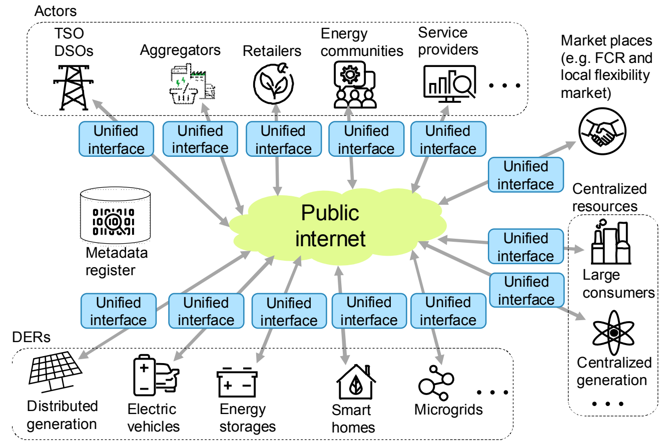

Figure 3. The concept of the decentralized information exchange architecture.

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. Each participant of the platform installs a gateway that maps the site specific protocol to the data model utilized as the common language of the platform. SmartAPI interface [1] has been selected. It utilizes a semantic data model where each message contains not only the payload but also the meaning of the payload. Payload can be encrypted with the SmartAPI and the messages are not bound to any specific format and they may be conveyed between actors with HyperText Transfer Protocol Secure (HTTPS) and MQ Telemetry Transport (MQTT) over Transport Layer Security (TLS), for example. In the implementation described in this paper, SmartAPI ontology is predominantly used but also other ontologies could be easily utilized because all messages contain also metadata describing what data the payload contains. This simplifies adding new type of data to the system if need for this arises since not all the information exchanges need to be redefined. All communication utilizes the public internet and no dedicated communication channels are built.

The system includes also a centralized metadata register that is used to store static DER data and to distribute encryption keys. Resources register to the metadata registry when they enter the system for the first time. At registration phase, basic information of the DER is added to the metadata register database and encryption keys are distributed. After the registration is completed, actors wanting to utilize DER flexibility (e.g. aggregators) can automatically discover the resource and obtain its basic data and encryption information on condition that the DER owner has given access rights to this actor or a group of actors to which the actor belongs. All information exchange after this point happens directly between actors and does not go through the metadata register. [2]

B. Securing information exchange

Cybersecurity is one of the key aspects in energy sector [3] and needs to be properly addressed for the decentralized architecture, depicted in Fig. 3. While information exchange by unified communication interface (SmartAPI) through an open networking infrastructure (public internet) facilitate interoperability between actors, it also increases the risk of cybersecurity threats to the system. Therefore, security solutions must be applied for the decentralized architecture in order to protect data against cyber-attacks and ensure reliable information exchange over the internet. Security measures can be employed at different layers in the OSI model (ISO/IEC 7498-1), such as Network, Transport and Application layer. The main issues addressed in the implementation of system described in this paper are access control, data authenticity and data malleability.

The access control is ensured by multiple layers of encryption of the communication. At the Transport layer of the OSI model the data is encrypted with TLS defined for HTTPS and MQTT protocols, that are used as transports. Additionally, security at Application layer level is implemented by encrypting the payload of the SmartAPI messages. Inside the payload the segments of data that communicate useful information are encrypted using hybrid encryption where the payload is encrypted by symmetric unique AES (Advanced Encryption Standard) key and the key itself is encrypted asymmetrically with RSA (Rivest–Shamir–Adleman) public key 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 public keys happens through requests to metadata registry actor for which the public key is pre-shared 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 public key. 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 implementation of these security measures is described in more detail in [2].

Security measures present security mechanisms at different layers of OSI model. These mechanisms may affect real-time requirements of the application because they add both processing times and communication headers to the information exchange in the decentralized architecture. However, there should be a balance between the security measures and real-time requirement of the use case. Further improvements to the cyber security 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.

III. Implemented Testing Platform

At the first stage, the decentralized information exchange platform has been used to implement a testing platform. The testing platform consists of geographically distant laboratories and enables advanced testing of future smart grid functionalities that can be quite complex and cannot be properly studied in a single laboratory or demonstration site.

The structure of the currently implemented testing platform is depicted in Fig. 4. The three geographically distant laboratories are used to represent the electrical grid and DERs, and system actors and market places are emulated. Two use cases have been demonstrated in detail. FCR use case demonstrates utilizing the developed information exchange platform for participating to the existing FCR markets following the current market rules. Distribution system operator (DSO) flexibility use case demonstrates utilizing DER flexibility for DSO purposes through conditional re-profiling purchased from flexibility market [4]. This paper concentrates on the FCR use case but Fig. 4 depicts also actors needed in the DSO flexibility use case.

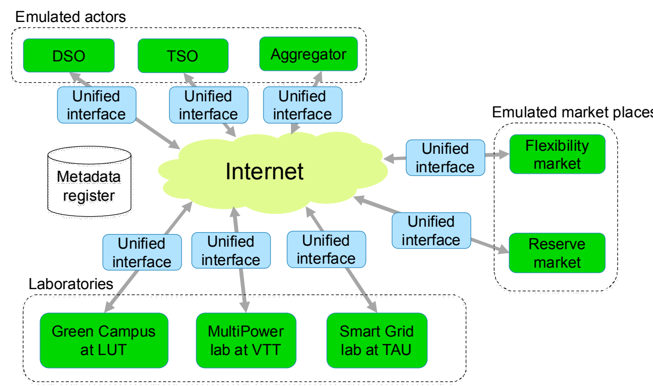

Figure 4. The implemented testing platform.

In the implemented testing platform, one of the laboratories emulates part of the electrical grid using a real-time simulator and the other two laboratories 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 geographical distribution of different actors participating to the test cases is represented in Fig. 5. 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.

IV. Example Use Case: Frequency Containment Reserve

The test case selected as an example for this paper considers utilizing DERs for frequency control through the FCR market. The actors participating to this use case include the two microgrids, aggregator and transmission system operator (TSO) and its FCR market. The microgrids have

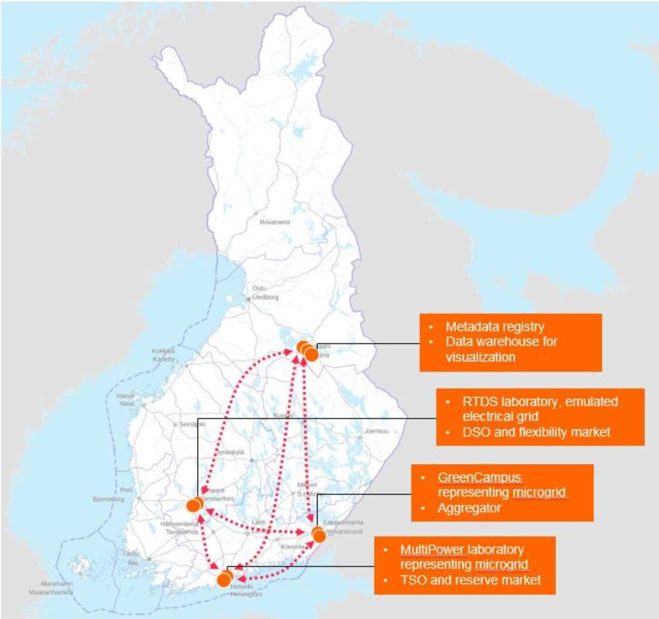

Figure 5. Actors and resources are geographically distributed.

controllable resources that are aggregated and offered to the reserve market by the aggregator.

A. Use Case Description

The FCR use case is implemented following the current FCR market rules so that the applicability of the proposed decentralized data exchange framework can be demonstrated also in the existing business environment. DERs participate to the market through an aggregator which would be the only option with the current minimum resource size limits in FCR market. The use case consists of two distinct parts: Market operations take place several hours prior to the operating hour and the DERs to be activated are determined during this time frame. During the operating hour, the resources that have been purchased switch to frequency control mode and operate based on local frequency measurement. Data exchanges between different actors are depicted in Fig. 6.

The market part of the use case starts by delivering flexibility information from different resources (in this implementation the two microgrids) to the aggregator since the implementation described in this paper does not include service providers as separate actors. The aggregator utilizes the flexibility information of all resources in its portfolio to form offers and sends these to the reserve market platform (RMP). At the same time, the TSO analyzes the amount of needed frequency support and sends bids to the RMP. When offers and bids are received, the RMP does merit order placement and notifies both the aggregator and the TSO about reserved products. Thereafter, the aggregator notifies microgrid management systems (MGMSs) and other types of resources about reserved products. The MGMSs in turn modify the operation plan of resources they are managing for accepted hours.

During operating hours, the resources purchased during the market part of the use case perform autonomous FCR-N control. The resources operate in frequency control mode i.e.

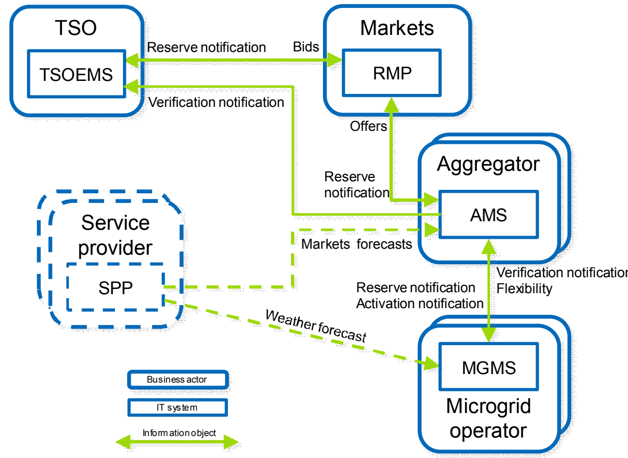

Figure 6. Information exchanges through the data exchange platform in the FCR use case. TSOEMS is transmissin system operator energy management system, AMS aggregator management system and SPP service provider platform.

control their real power based on a local frequency measurement. No data exchange is needed during this operation. After operating hours, different sites deliver product verification information to the aggregator that gathers them for later use.

B. Test Case Implementation

Testing was divided into communication and open-loop testing phases in order to at first allow continuous and unsupervised testing of communication and then verify correct operation of hardware. In communication tests simulated DERs are used and in open-loop tests real hardware is included as a part of testing. The MultiPower and GreenCampus laboratories represented microgrids in the test set-up and one controllable resource was utilized from both laboratories. At GreenCampus, battery energy storage system (BESS) was selected and at MultiPower a controllable load was used. 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.

In communication tests, all data exchanges through the data exchange platform are conducted similarly as in business use. Proper operation of all actors is verified and test results are collected by running test cycles continuously. In addition to verifying that data exchanges operate as expected, test objectives include also evaluation of data integrity and transfer times of communication between the actors. Tests 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.

In open-loop tests, the real hardware components (battery energy storage and controllable load) are utilized instead of simulated DERs but otherwise the set-up is similar to communication testing. The market part of the use case determines whether the DERs are switched to frequency control mode. During the operating hours where the resources are activated, the real power output depends on the locally measured frequency. A predefined frequency sequence is utilized in the tests and naturally the same time synchronized sequence is executed at both laboratories. The frequency sequence is based on a frequency measurement during a frequency disturbance caused by an event in a large nuclear power plant. Transmission system model is not included in the test set-up and, therefore, the power changes do not affect the frequency. For FCR use case with a low number of small resources included, this set-up does not lead to any error. Some other use cases require closed-loop testing.

C. Results

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 Fig. 7 and from GreenCampus in Fig. 8.

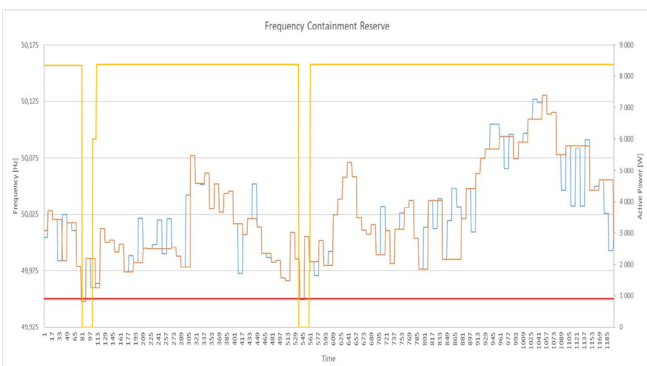

Figure 7. Open-loop testing results from MultiPower. Power measurement of the controllable load (yellow), frequency threshold to disconnect/connect the load (red), predefined frequency sequence (blue) and the frequency seen by the load (orange).

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 the provided reference signal. This verifies that the communication of registration, market and control commands occurred in a timely manner despite the test

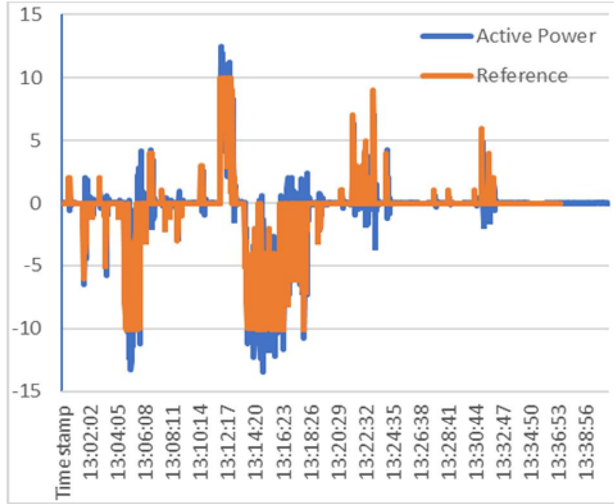

Figure 8. Open-loop testing results from GreenCampus. Delivered active power measurements on output of BESS. Vertical axis is in kW.

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.

V. Conclusions

This paper describes development and demonstration of a decentralized information exchange platform that enables more efficient utilization of DERs in system operation. The platform concept itself is technology neutral at all SGAM [5] layers and can support multiple kind of smart grid architectures (e.g. centralized, completely distributed or hybrid decision making) defined by use cases. Its operation has been demonstrated with two detailed use cases of which the FCR use case follows the current market rules and the DSO flexibility use case describes operation that does not exist yet. Hence, the proposed decentralized information exchange architecture enables both the currently used business models and completely new smart energy functionalities.

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