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Integrated business platform of distributed energy resources – Case Finland

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Abstract

The present energy system is facing various challenges in the near future due to changing demand and productions structures. Novel ideas are required to address the control of large number of the flexible resources. The paper aims to introduce integrated business platform of distributed energy resources in Finland. The platform is used to exchange information between laboratories, pilots, and actual facilities of all market participants. The paper describes the bare minimum information exchange requirements of some use cases for the integrated business platform to enable novel business opportunities for monitoring, verification, and application of flexibility services of microgrids and energy communities for the purposes of transmission and distribution grid management. The proposed information exchange platform is based on definition of use cases for the smart grid architecture model.

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1. Introduction

The present power system will be facing various challenges in the near future because of changing demand and production structures. The amount of renewable production is rapidly increasing and causing intermittency issues for the energy and power balance. This leads to a growing need for regulating power from present and new

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resources. While production is changing, also the consumption structure is starting to lean toward power-intensive from energy-intensive consumption devices [1]. This is a result of multiple factors, such as heat pumps, energy efficient houses, and charging of electric vehicles. The changes that the power system is facing are of both a technical and a business nature. Many of the new resources are seeking options to participate in the market to tackle technical issues that the power system is currently starting to face.

The role of microgrids, energy communities, and aggregators (virtual power plants) is emphasized in the electrical system because they offer an opportunity for new kinds of flexibility but also introduce new challenges to the energy system management. The 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 barriers is the lack of a widely accepted interoperable information exchange interface that is easily accessible and meets the business needs of all parties involved in the energy system.

The article addresses an integrated business platform of distributed energy resources, the aim of which is to enable information exchange between energy market participants. The first version of such a platform will be implemented to integrate a number of smart grid demonstration sites in Finland to develop, test, pilot, and finally, commercialize new smart energy system functionalities consisting of interactions and impacts of multiple participants. The development of such a system starts as a national platform in Finland, but the platform will be designed to support Europe-wide adoption of the system. The focus of this article is especially on the information exchange architecture of heterogeneous market participants, with the aim of enabling novel and coordinated business in the energy sector.

The paper describes the bare minimum information exchange requirements of some use cases for the integrated business platform to enable novel business opportunities for monitoring, verification, and application of flexibility services of microgrids and energy communities for the purposes of transmission and distribution grid management. The proposed information exchange platform is based on definition of use cases for the smart grid architecture model.

Developing platforms that allow to evaluate the direct effects and interactions of different resources in a real-world environment can help to identify and analyze alternative future scenarios and paths of the future energy business. In the project, such a testing platform will be built by combining laboratories, simulation resources, and pilots of the project research partners. Even though some of the related pilots are already extensively studied at the moment, the element of cooperation is missing as most of these pilots focus on individual local applications and lack a comprehensive view of the multiple participants of the energy system.

The HEILA project defines multiple functionalities and requirements that allow integrating distributed energy resources (DERs) into different business models of the electrical energy system and determines the information exchange platform to implement these functionalities. The obtained information exchange platform will be the basis for the implementation of an IT solution for the target development and demonstration of the integrated platform. A special objective of the project is to establish an interface between geographically dispersed microgrids to a "control hub", which provides an interface of metadata and register information of DERs and their flexibility properties for flexible resources (DERs and microgrids), smart energy system functionalities, and market players (such as aggregators, distribution system operators (DSOs), and the transmission system operator (TSO)).

2. Operation environment and piloting resources

The energy system is undergoing a major transition. As mentioned above, the production and demand structure in the energy system is changing and the whole energy system is facing new challenges such as a rapidly increasing amount of inflexible production forms, constantly decreasing inertia, and high supply reliability demands.

The present research aims at offering flexible solutions for adding active resources to the energy system. The goal is approached by introducing several laboratory pilot environments to a novel communication and information exchange platform. In addition to acting as an information exchange interface for the resources in the energy system, the platform is designed to facilitate the participation of new participants and functionalities in the energy system and energy marketplaces. The proposed platform is described in more detail in section 3. It is developed and tested by using laboratory and microgrid resources provided by Lappeenranta University of Technology (LUT), Tampere

University of Technology (TUT), and VTT Technical Research Centre of Finland Ltd. The laboratory pilot environments are geographically apart from each other, which makes the test setup more realistic.

2.1. Green Campus in the Lappeenranta University of Technology

The LUT Green Campus is an umbrella project of LUT that includes for instance a laboratory environment to demonstrate a variety of microgrid functionalities in power grids and communication networks. The laboratory resources are located in Lappeenranta in southeastern Finland. The LUT Green Campus grid consists of a 132 kWh battery energy storage connected to an LVDC test network, 206 kWp of solar PV, 20 kW of wind power, a smart EV charging pole, and several external data streams to enable new control schemes. The laboratory setup has an extensive collection system for research data.

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

2.2. Smart Grid Laboratory at Tampere University of Technology

The smart grid laboratory of TUT represents a distribution grid in the demonstration. A real-time digital simulator is used as a backbone of the system. The simulator analyzes the distribution grid and the connected DERs and microgrids in real time. The input signals for the simulated DERs and microgrids (running on other demonstration sites in reality) are received through the information exchange platform. Similarly, the output of the distribution grid analysis is provided to other demonstration sites to modify grid properties in the DER or microgrid connection points by a grid emulator. It is noteworthy that the proposed system will not be used for transient performance studies, but rather for the analysis of the interaction and cooperation of market participants.

Furthermore, a hierarchical and distributed distribution grid management solution is in use on the TUT demonstration site [2]. The automation solution is based on commercial IEDs and prototype Substation Automation Units located at primary and secondary substations. The solution possesses data collection, storage, analysis, and reporting capabilities, in other words, facilitates a hierarchical and distributed grid automation system. The laboratory is described in detail in [3].

Congestion management of a medium- and low-voltage grid applying the DSO’s resources and flexibility services from the local flexibility market is the main use case to be demonstrated in the project. Again, information exchange between the DSO and the local flexibility market is carried out through an information exchange platform where aggregators, who represent DERs and microgrids in different markets, give their bids. From the DSO’s perspective, DERs and microgrids are controlled indirectly by the market. A modified version of the congestion management concept presented in [4] is used in the demonstration.

2.3. MultiPower Laboratory at VTT

The MultiPower laboratory of VTT, located in Espoo, is a combination of multiple independent testing facilities, which can be connected together if required. The whole laboratory environment contains different types of generation, load and storage units, and measurement, control, and protection systems. In the first phase, only a part of the laboratory is connected to the developed business platform through the information exchange interface. The connected testing facility consists of an LV network, which contains a micro-scale PV unit, a PV emulator, resistive and inductive loads, and a connection point for external devices. A grid emulator is also available, making it possible to control the voltage and frequency of the laboratory network. The measurement, control, and protection systems contain environmental measurements for the PV system, an 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 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.

3. Proposed information exchange platform

The platform is used to exchange information between laboratories, pilots, and actual facilities of all market participants (Figure 1). The platform itself does not implement the use cases, but enables information exchange of market participants, DERs, and the like to test and demonstrate various use cases. The platform is also technology neutral at all SGAM layers and can support multiple kinds of smart grid architectures (e.g. centralized, completely distributed, or hybrid decision-making) defined by the use cases.

Each participant of the platform needs a gateway (Smart API interface [5] defined for a specific use case) to integrate the laboratory or pilot site into the platform. The gateway maps the participant's site-specific protocol to the data model of the platform defined by the Smart API ontology. On the common side of the platform, everyone will "speak the same language". Thus, every participant will understand not only the syntax but also the semantic content (canonical data) of the exchanged information. The payload is the actual content of the message, while other parts of the message are headers and metadata needed to enable payload delivery. The gateway also provides an easy way to control which data of the demonstration site will be published to other participants. It also simplifies integration of the demonstration site into the platform as no changes are required on the site itself, but only a server communicating with the site resources is needed. The site resources can be of almost any kind, as shown in Fig.1.

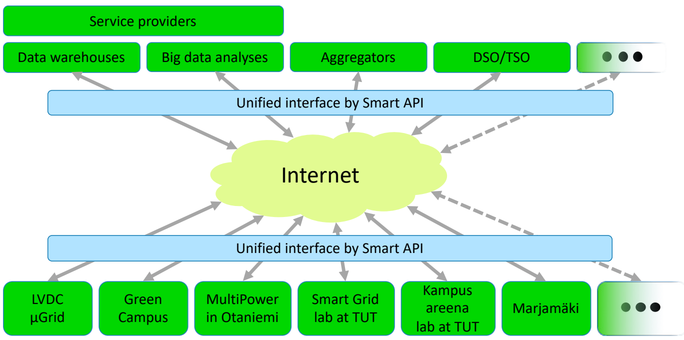

Figure 1. Example of platform utilization

Fig. 2 demonstrates the technical content of the platform in a detailed way. The gateway is implemented as a Smart API client/server based on an open source Smart API library. The Smart API library is aimed to exchange information between energy system participants within a dynamic environment, and it has an extendable data model for the energy domain. Further, the Smart API also hides the complicated semantic data structure, which makes it easy to use. The security features of the Smart API are basic HTTPS, messaging can be encrypted and signed, and authenticated by using OAuth2.

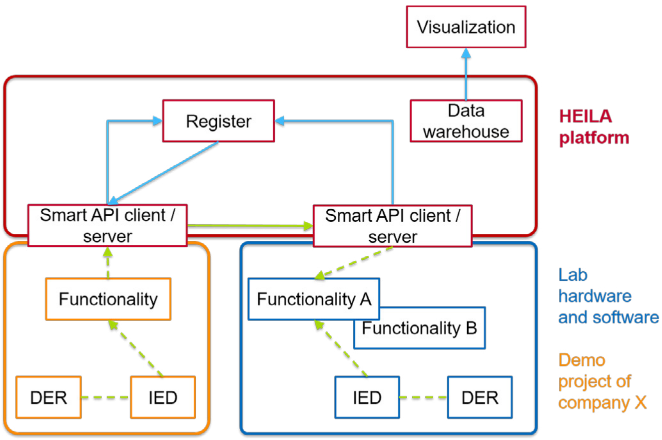

Figure 2. Main parts of the platform and integration of demonstrations, pilots and laboratories to platform.

In order to send messages between Smart APIs, a register is needed to organize and manage registration to the platform and discovery of resources/services included in the platform. The register contains metadata (information about the data themselves) of resources/services available in the platform. The metadata describe a resource (e.g. title, abstract, author, and keywords), provide structural information (types, versions, relationships, and other characteristics of digital materials), and administrative information (e.g. when and how the resource was created, file type, and other technical information, and who can access it). The blue arrows in Fig. 2 represent the visualization, registration and discovery parts of the platform.

When two Smart APIs have detected each other and they have a contract to exchange information, the messaging between them is carried out directly (green arrow). The information exchange can be cyclic, event based, or based on subscription. Internally, each demonstration, pilot, or laboratory (orange and blue sections in Fig. 2) arranges the information flow independently from the platform (dashed green arrows). The platform allows a variety of resources to be connected with aggregators, DSOs, retailers, or some new actors (even outside the energy sector). In this way, it may emulate existing hierarchical management systems such as energy balance management and settlement, or distribution grid management. New elements such as microgrids providing flexibility services for the local flexibility service market can be added to the platform to emulate/simulate such a functionality and interactions with other participants. Resources can also be connected in a completely new way, for instance, by implementing peer-to-peer communication between resources. Because one of the main targets of the platform is to use it as the first version of the Finnish smart grid demonstration platform, the platform has to be secure, scalable, and easy to use. Basic cyber security has been built into the Smart APIs (authentication, encryption). The user control is ensured by the mandatory use of the register that contains metadata for access control allows to control who has access to specific data.

In general, the scalability of the platform is very difficult to determine, but the platform is expected to be well scalable because of the distributed system architecture. In practice, the implementation of use cases and Smart APIs sets for instance the limit on how frequently and by how many clients the platform can be polled. These aspects, however, can be influenced in the design phase of a use case, and therefore, the platform should include and collect good practices for implementation.

4. Data exchange requirements in particular use cases

The definition of the HEILA platform is based on a procurement of multiple functionalities and requirements in the form of use case descriptions. In the first phase, three distinct use cases were chosen to be further reviewed from the viewpoints of three operators (System Operator, Aggregator, and Microgrid Operator). As a result, nine detailed use cases were formulated, which depicted the connections, interfaces, and internal functionalities of the actors.

In the next phase, the detailed use cases were combined into two implementation use cases that would demonstrate the operation of the platform. The first implementation use case presents the operation of different actors on a frequency containment reserve (FCR) resembling the present one. The other implementation use case illustrates the information exchange needed for actors operating in a new kind of marketplace, where DER owners can offer their flexible capacity to a local flexibility market through an aggregator. The first implementation use case is referred to as "FCR" and the latter one "DSO Flexibility", based on the idea that in the future the DSOs may need a local market for local voltage control.

The implementation use cases are the first concrete step in building of the platform. They are used to test the underlying theory in practice. The use cases produce important evidence of how the system and all its interfaces work. Moreover, these use cases operate in different time frames and thereby introduce diverse requirements for the data exchange. Thus, they can be used to verify the multi-objective performance of the platform during their simultaneous operation. Use case interactions

4.1. Use case interactions

While more detailed information about the implementation use cases can be found in [6],[7], this section focuses on a general description of the information exchange between the actors of these use cases. These actors are illustrated in Fig. 3 and represented by automation systems and semantically linked business entities. Considering that each automation system will be implemented by different pilot site and lab, Fig. 3 essentially shows how the labs and pilot sites will interact through the HEILA platform in the context of implementation use cases. Similarly to the description in Fig. 2, the direct information exchange between the automation systems through the Smart API is represented by solid green arrows while internal interaction are defined by dashes green arrows. The information exchange take places in different time frames and can be divided in day-ahead, intra-hour, and real-time slots.

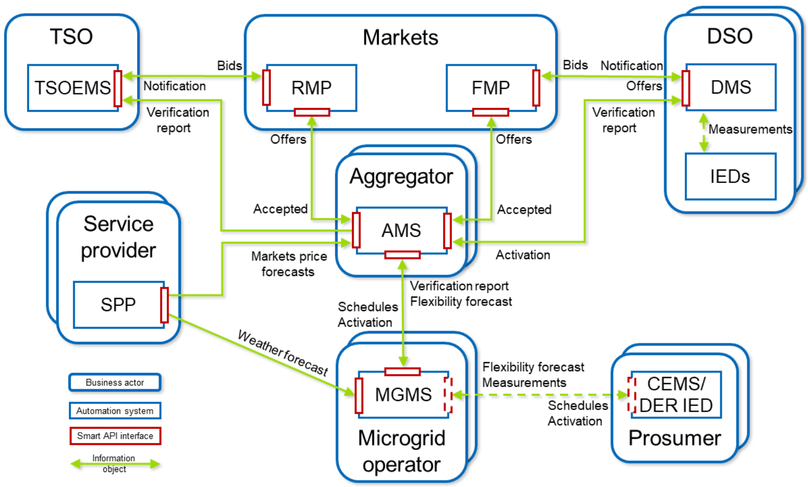

Figure 3. The general view on the structure of implementation use cases in HEILA project.

4.1.1. Day-ahead and intra-hour time frames

The market structure of microgrid aggregation used for the use cases is scalable and can provide multiple market interfaces for the microgrid resources simultaneously. Consequently, the day-ahead and intra-hour time frames are united as they consist of similar market functional processes and exchange information models for both of the use cases. Such processes start as a continuous sequence of the interactions of the aggregator management system (AMS) with the microgrid management systems (MGMSs) and the service provider platform (SPP). Because the reserve and flexibility market platforms (RMP and FMP) operate in different time frames, the exchange information is extendable to contain short-term and long-term forecasts of the microgrid flexibility and market prices. Thus, in case of simultaneous operation of both use cases, the AMS is able to optimize commercial planning of microgrid flexibility considering the benefits of multiple markets. Rest of the interactions related to the market are needed for the bidding process of grid operators and notification of the AMS about the accepted offers and the MGMS about the updated schedules.

4.1.2. Real-time frame

The direct information exchange in real-time has two main aims, which are activation of the purchased microgrid resources in real time as a conditional re-profiling product and continuous real-time verification of corresponding microgrid actions. The activation is only utilized for the DSO Flexibility use case while the verification is needed in both use cases. Circular information exchange enables the DMS to estimate the reaction of the grid on sent commands and coordinate its own actions by setting new operational points for microgrids or using other resources. Real-time verification of continuous active power regulation service of DERs within the microgrid provides the reports for the TSO energy management system (TSOEMS) about maintained and activated reserves.

This structure of direct information exchange can be also expanded to interactions between grid operators as well as between the markets to improve visibility and coordination for the actions of each other. The information exchange approach applied in HEILA use cases reduces the load on the interfaces of automation systems of grid operators while enable visibility of the microgrid reserves and their operational state.

4.2. Use case data models

The data models applied in the implementation use cases are flexible to enable diverse data handling. They contain a minimum amount of information required to ensure a sufficient level of control for DERs. Many of the exchanged messages are of the same structure and can be further expanded. For example, Offer IO in Fig. 3 contains Offer Id, Flexibility type, power, start and stop times, and price information. Most of these data are reused when a product is either reserved or activated. Furthermore, IOs contain semantic information about units, quantities, and data types as they use SmartAPI and Quantity, Unit, Dimension and Type (QUDT) ontologies. The weather and price forecasts and the measurements use an existing data model, and are therefore not presented here.

The implementation use cases include technical requirements for communication between different actors. Transfer time, rate, synchronization accuracy, and availability set the minimum requirements for the performance.

5. Conclusion

In the paper, the need for a novel information exchange platform in energy system was recognized. The information exchange platform was introduced and defined. The paper defines multiple functionalities and requirements that allow integrating DERs into different business models of an electrical energy system, and determines the information exchange platform to implement these functionalities. The Smart API open source library was chosen as the common interface among all the resources interacting with the platform. The actual platform pilot sites and demonstration use cases were introduced in brief. The project continues by an implementation phase followed by a testing phase, where the actual operation of the platform is validated.

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