ARCHITECTURE OF INTEGRATED BUSINESS PLATFORM OF DISTRIBUTED ENERGY RESOURCES AND INTEGRATION OF MULTIPOWER LABORATORY

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ABSTRACT

This paper focuses on description of platform a architecture model, which promotes specific smart grid use cases, and integration of MultiPower research laboratory as a part of the platform. The platform is developed in HEILA (Integrated business platform of distributed energy resources) project and aims to merge diverge pilots and laboratories into an integrated energy system platform by means of Information and Communication Technology (ICT).

The paper provides detailed description of the architecture model focusing on, but not limited to, integration and management of geographically distributed microgrids, flexibility related services on distribution level, and integration process of MultiPower laboratory.

The main benefits of this paper include the description of platform architecture model focusing on flexibility services on distribution level. Other important result is the description of integration process, which provides details and supplementary information about practical implementation and system performance.

INTRODUCTION

Transition in the energy sector led by integration of Distributed Energy Resources (DER) and shift from traditional electrical grids towards smart grids calls for new energy management, ICT and business solutions. Furthermore, the wide range of possible smart grid applications as well as complexity of smart grid characteristics, novel business models of energy systems and swift introduction of innovations in energy sector require means to develop, test and pilot new smart grid solutions.

This paper is written as a part of a research project called HEILA (Integrated business platform of distributed energy resources). The research project aims to connect diverse laboratories and pilots into an integrated energy system to host potential smart grid applications, which intend to incorporate DERs into novel business models of energy systems [1].

This paper focuses on describing the information exchange architecture model for the platform and testing the first versions of software components. This paper addresses problem with methodology [1], which bases on use case methodology and Smart Grid Architecture Model (SGAM) [2], elaborated in HEILA project and by implementing necessary software components into VTT's MultiPower laboratory equipment to demonstrate basic operation.

ARCHITECTURE OF INTEGRATED BUSINESS PLATFORM OF DISTRIBUTED ENERGY RESOURCES

This chapter presents the developed architecture model with SGAM. Generally, the architecture model presents domain (e.g. Distribution Management System (DMS)) and function (e.g. weather forecast) specific systems and leaves out other systems focusing on administration features such as clock reference and authentication and authorization systems. Furthermore, the presented architecture model bases on DSO Flexibility use case.

DSO Flexibility

The main target of the use case is to improve power quality in the network with the use of flexibility that Prosumer possesses. Aggregator, Flexibility Market Operator (FMO) and Service Provider supply services that support realization of the main functionality. The DSO Flexibility use case is a High-Level Use Case (HLUC) and it invokes Primary Use Cases (PUC), for example Microgrid Monitoring use case. Figure 1 illustrates goals, business use cases, HLUCs, business actors and relations for the DSO Flexibility use case. Moreover, Table 1 presents descriptions for logical actors (devices and systems) in the use case.

Business layer

The Aggregator acts as medium between the FMO and actors providing flexibility. The FMO links the Aggregator and DSO. Furthermore, the Microgrid Operator (MO) manages certain part of Prosumers network. By utilizing flexibility, the DSO may improve power quality, performance indexes and efficiency in distribution network, thus benefiting economically.

Table 1. Logical actor descriptions.

Actor	Type	Description
Intelligent Electronic Device (IED)	Device	A microprocessor-based controller, smart meter or general device for control & monitoring.
Customer Energy Management System (CEMS)	IT System	A generic information system for monitoring and control of customer side's flexible resources that optimizes their consumption and generation portfolios to sell this flexibility to upwards stakeholders.
Service Provider Platform (SPP)	IT System	A system that provides the forecasts of weather and prices of flexibility market.
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 markets and provide the management of such services.
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's resources in flexibility services.
Flexibility Market Platform (FMP)	IT System	A system for trading of flexibility between Aggregators and other market actors.
Distribution Management System (DMS)	IT System	A collection of applications within the system designed to use Microgrids' flexibility for the support of the quality of supply of distribution network.

Furthermore, by utilizing flexibility the DSO may have access to local control indirectly as it may send commands to other actor's systems after purchasing a product. The Aggregator may do business by providing flexibility and promote green choices and efficiency. By providing flexibility, the Prosumer may decrease payback time of equipment, have access to energy market and reduce carbon footprint. Additionally, the MO, Service Provider and FMO may provide services that support use of flexibility and/or expand their businesses.

Business Use Cases (BUC) Flexibility Services of Microgrids and Network Management accommodates motives and business goals for cooperation for different actors. HLUC Flexibility management of Microgrids, which is superior to similar use cases as the DSO Flexibility, invokes the DSO Flexibility as shown in the figure. The Aggregator and MO have a contract so the Aggregator offers products that the MO possesses and both benefit in terms of money.

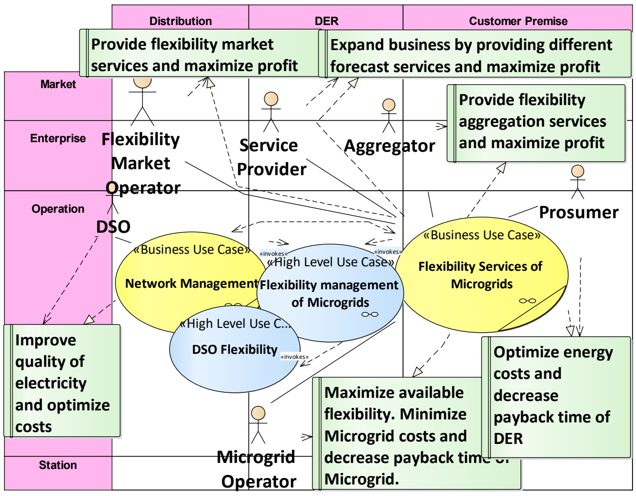

Figure 1. Business layer.

Furthermore, the MO can be a company or a housing condominium, for example, or any party equivalent to them who has electrical equipment interconnected to the system and they are managing the equipment. In case the Prosumer has required capability, it can take on roles of the MO and Aggregator.

Function layer

The DSO Flexibility use case and all of the PUCs locate on the function layer as Figure 2 illustrates. Furthermore, red lines indicate function interrelations. Function positioning especially promotes decentralized data acquisition and control instead of traditional decentralized data acquisition and centralized control. However, it is not a requirement.

The Microgrid Monitoring takes care of delivering measurements, operation plans and notifications to MGMS level for utilization. Data Acquisition provides measurements and states to DMS with DSOs own equipment. The Market Operations enables interaction between the DMS, AMS and FMP. Moreover, it covers participation to different markets, for example Day Ahead and Intraday markets. The Offer Ranking in the FMP organizes offered flexibility and ensures cost-effective use of offered power. With the State Optimization, the DSO defines required amount of flexibility. The Flexibility Management utilizes different forecasts, covers optimization tasks to calculate flexibility offers for different markets, and schedules resources when offers are accepted. The Flexibility Market Price, Weather and State Forecast and Schedule & Dispatch to some extent, provide estimations so other use cases may utilize them and allow more consistent and efficient operation of the grid.

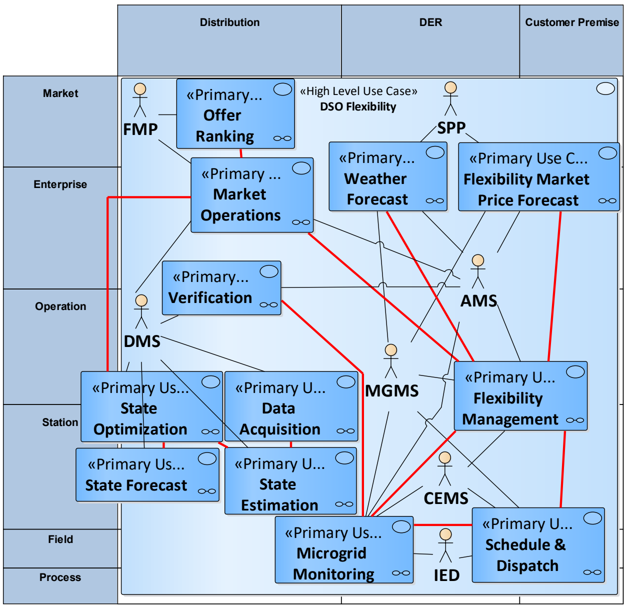

Figure 2. Function layer.

Moreover, the State Estimation provides information when to activate flexibility products. The Verification confirms that the purchased product was activated and may be utilized for commercial purposes too.

Component layer

Components of the MultiPower laboratory test setup and other actors' components for the DSO Flexibility use case locate on the component layer as Figure 3 displays.

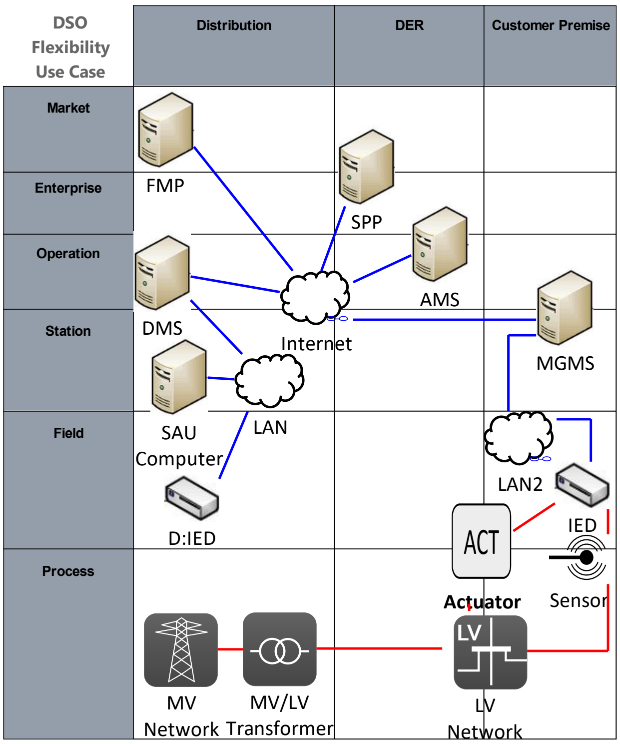

Figure 3. Component layer.

The figure presents also Substation Automation Unit (SAU) that DMS utilizes. Blue and red lines indicate ICT and electrical connections, respectively. In addition, the Actuator represents a circuit breaker that the IED manages in the MultiPower. The test setup is simplified for first tests (and illustration purposes) and it does not include all hardware from laboratories.

Information & Communication layer

Information Objects (IOs) shifting between the logical actor's hardware are presented in Table 2 and Figure 4. Furthermore, not all of the IOs refer to actual message types since some of them are clustered for illustration purposes. Downstream from the MGMS level, content of information flows depend on features of devices. Blue and black lines (solid) indicate information flow and association, respectively. The Measurements and Control Signals IOs group different measurements, states, different control signals and setpoints, respectively.

Table 2. Information objects.

Information object	Description
Measurements	Current and voltage Apparent, active and reactive power Power factor Circuit breaker state
Control Signals	Control signal Setpoint
Operation Plan	Load/generation schedule for certain period of time
Flexibility	Id, flexibility type, power, start and stop time
Offer	Id, flexibility type, power, start and stop time, price
Offer List	Offer list. Location and price dependent
Bid	Id, flexibility type, power, start and stop time, price
Weather Forecast	Weather forecast for certain period of time
Reserve Notification	Id, flexibility type, power, start and stop time, price. Reserve notification that is provided after market clearance
Activation Notification	Id, flexibility type, power, start and stop time. Activation notification that is provided when DSO activates product
Verification Notification	Id, power measurements, start and stop time, time step between measurements. Verification notification that is provided after product is activated
Flexibility Market Price Forecast	Flexibility price forecast for certain period of time

The figure 4 displays IOs in a situation where MGMS sends flexibility information to the AMS, who then decides commercial aspects for the flexibility and offers it to suitable market. Therefore, with this situation the MGMS does not need price forecast from the SPP. Other option is that MGMS receives price forecast and resolves commercial aspects completely itself and then delivers flexibility information to the AMS or to the market directly. In other words, these matters highly depend on features and connections of devices and choices of the Prosumer.

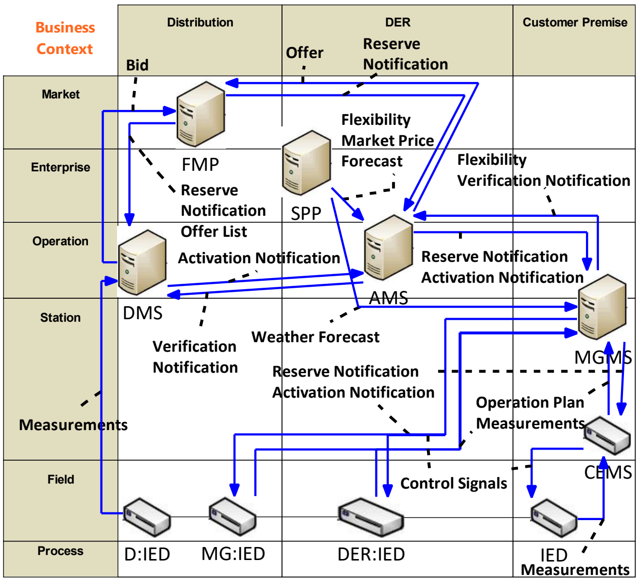

Figure 4. Information layer.

Figure 5 illustrates communication protocols and data model standards used between the logical actors. The platform utilizes SmartAPI [3] in communication. The SmartAPI exploits semantic data, so messages contain payload together with exact meaning of payload. Payload can be also encrypted with the SmartAPI. Additionally, 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.

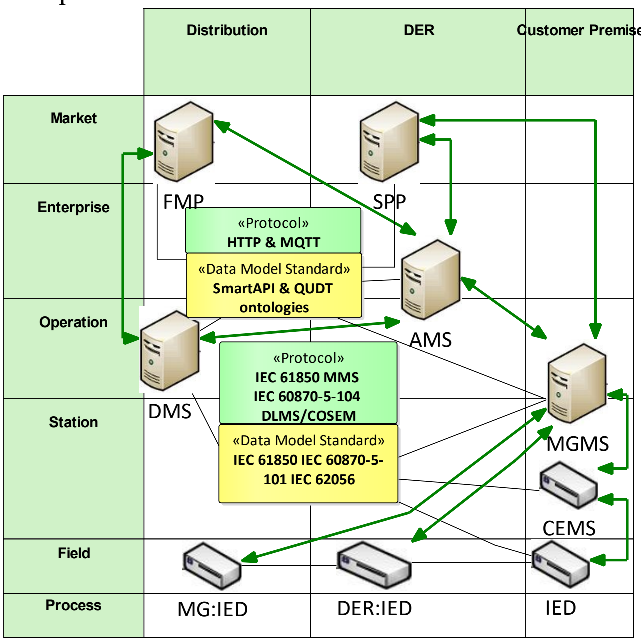

Figure 5. Communication layer & standard mapping.

For connections from the field protocol depends on equipment that is used. In this case, downstream from the MGMS level communication protocol is IEC 61850 MMS, IEC 60870-5-104 or DLMS/COSEM.

INTEGRATION OF MULTIPOWER LABORATORY

This chapter presents integration task and test set-up for initial tests in the MultiPower laboratory environment. Furthermore, this chapter provides description of configuration, testing activities and results. Figure 6 highlights the integration problem (in orange), test set-up in the MultiPower laboratory and part of the platform (purple) that will be used in tests.

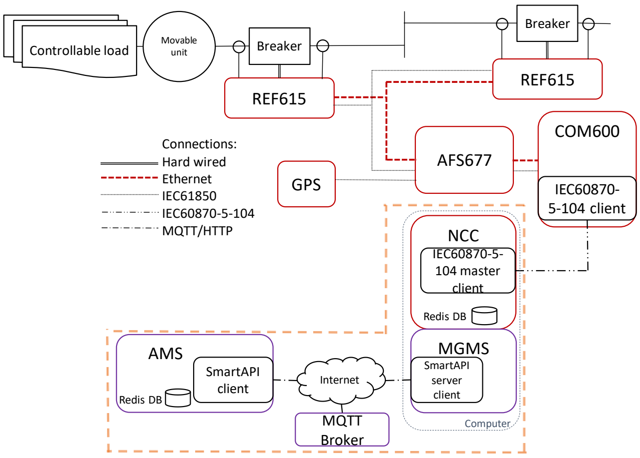

Figure 6. MultiPower laboratory test set-up.

As shown in the figure, the COM600 is connected to Network Control Centre (NCC) via IEC 60870-5-104 client. Moreover, here the NCC is not any kind of control center and it is illustrated just to indicate link with available COM600 material.

Configuration

Configurations were made to the computer in the MultiPower laboratory and for another computer that represents the AMS in testing. Chosen language for testing was Python programming language. To run test scripts on the computer in the MultiPower laboratory, installing several programs on the computer was necessary.

Python release 2.7.14, Windows x86-64 version, was downloaded and installed on the computer. Next, newest Microsoft Visual C++ Compiler for Python 2.7 (version 9.0.0.30729) installer was downloaded and the compiler was installed. A package management system pip was used to install SmartAPI, web.py, paho-mqtt and redis to the computer in MultiPower. Finally, repeating configuration process for another computer is necessary in order to use it to represent the AMS in different location.

Testing

Testing covers transferring use case related messages between the MGMS and AMS and controlling process. Furthermore, for the DSO Flexibility use case steps related to transferring Flexibility and Activation Notification messages between MGMS and AMS are considered as part of the tests since actor processes are not developed yet within the platform. However, it confirms proper equipment operation in the MultiPower.

DSO Flexibility test started from sending Flexibility IO to AMS and continued with receiving Activation Notification IO from AMS as MGMS. Activation Notification IO lead to a control command that the IEC 60870-5-104 client eventually sent to the COM600. Then, confirmation that field devices operated correctly, was collected from circuit breaker status information in the COM600. With a separate Redis client the MO can monitor the value of control command information in its database and simultaneously observe the changes in the field process. Table 3 presents average transfer times with 10 attempts between REF615 and MGMS database and between the MGMS and AMS databases for different messages in monitoring and control direction.

Table 3. Transfer times.

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	Activation Notification, AMS database → MGMS database		Feeder circuit breaker position, MGMS database → REF 615
Protocol	MQTT		IEC 60870-5-104
Transfer time(ms)	36		584

Information and timestamp that the circuit breaker position command was executed properly were gathered from circuit breaker position status in COM600 so transfer time in that case is pessimistic.

CONCLUSIONS

The produced architecture model and description presents with five different layers how Prosumer, MO, Aggregator, DSO, Service Provider and FMO from the DSO Flexibility use case work together to benefit from flexibility related services. The architecture model also shows functional requirements and ICT architecture for the use cases.

The architecture model presents HTTP and MQTT as protocols above the MGMS level and self-descriptive messaging with utilization of Smart API. This way messaging is secure and flexible and new additional services can be developed in a way that is more straightforward. The function positioning with two-way communications in the architecture promotes decentralized data acquisition and control instead of traditional decentralized data acquisition and central control. Additionally, the architecture hides legacy systems. As a result, the architecture may promote development and utilization of flexibility related services and products. However, it should be noted that the architecture model have to be further developed in case of other actors and use cases.

The integration included configuration of the computer in the MultiPower, programming functions that read, write and deliver information within the system and simple tests with another computer to demonstrate operation and to collect test results.

The MultiPower laboratory environment was integrated with present version of the platform as existing equipment in the MultiPower can be monitored and controlled. Although, the platform development is still ongoing and modifications and additions are foreseen, which means that also the connections with the MultiPower will be revised and further developed in near future. Nevertheless, tests demonstrate that the process on field can be controlled with the system as result of to be developed actor processes. Additionally, tests provide overall and section delay information that can be taken into account when designing processes within the system with different time scales or new use cases.

In further research work in HEILA project, necessary security measures and enhancements to server and client code (e.g. payload encryption) will be considered.

ACKNOWLEDGEMENT

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