DEMONSTRATING ACTIVE DISTRIBUTION GRIDS AND ACTIVE DEMAND

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ABSTRACT

Active distribution grids and active customers require a rethinking of ICT tools and architectures in order to connect systems, platforms and actors previously unable to exchange information across domains of the energy business. This paper presents results from an R&D project focusing on developing a reference architecture for an open smart grid middleware, able to cope with the wide range of services necessary to integrate both DSOs, retailers and consumers as well as new actors (such as aggregators and prosumers) to a common framework. Such a framework is necessary to develop, scale and design future energy-related services to customers and other relevant stakeholders in the energy system operation.

NOMENCLATURE

API – Application Programming Interface
AMQP – Advanced Message Queuing Protocol
CIM – Common Information Model (IEC 61968)
DER – Distributed Energy Resources
DMS – Distribution Management System
DSO – Distribution System Operator
LCC – Life Cycle Costs
MW – Middleware
NTE – Nord-Trøndelag Elektrisitetsverk
OPF – Optimal Power Flow
RD&D – Research, Development and Demonstration
REST – Representational State Transfer
SCADA – Supervisory Control and Data Acquisition
SDI – Semantic Device Interface

INTRODUCTION

Efficient grid operation and integrated demand side have gained a lot of focus over many years. The same applies for standardization and interoperability. This paper focuses on how interoperability among actors and stakeholders can be achieved through an open reference architecture in order to integrate active distribution grids and active demand.

The results and experiences gained from demonstrations, are mainly developed through an EU-funded R&D project named e-GOTHAM [3] (2012-2015) using Demo Steinkjer [1] as living laboratory. Many of the activities in this project focus on communications, open source development, middleware frameworks, multisided business models and standards. In this paper, emphasis is put on a new dynamic grid tariff developed in the project. Optimization and grid management through the new tariff is enabled through an open ICT architecture and development of an open middleware architecture.

DEMO STEINKJER AS A LIVING LAB

Demo Steinkjer [1] is one out of four national smart grid laboratories/living laboratories in Demo Norway[2] and is hosted by NTE (a regional multi-utility).

Demo Steinkjer is currently operating as pilot/living lab for many different EU and nationally funded RD&D projects, as well as commercial development project for different vendors. Demo Steinkjer contains a versatile infrastructure for both grid-related and customer-focused RD&D projects.

The Demo Steinkjer area includes 800 electricity customers (both households and commercial buildings). Modern smart meters recording energy consumption every hour are installed in the buildings. These hourly-based time-series are uploaded once a day to a cloud-based storage service/database specially designed for time-series data. In addition to these 800 meters being uploaded once a day, the living laboratory also have 10 meters recording the consumption every minute. These meters make it possible to test and validate the ICT architecture and operations in real time. Before publishing the data, it is managed in two important ways:

- The data is anonymized so that individual customers cannot be traced.
- The data is standardized and structured following the Common Information Model (CIM), more precisely the IEC 61968-9. This part focuses on “Meter reading and control”.

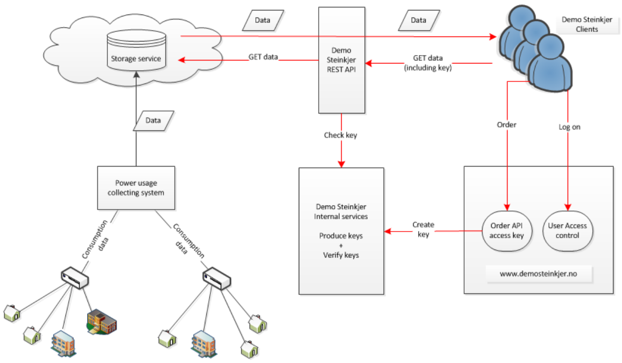

Figure 1: Demo Steinkjer smart meter cloud service

The standardized consumption data are made available for RD&D partners through Demo Steinkjer's REST API[1], see Figure 1.

SMART GRID BARRIERS

Many barriers for large-scale introduction of smart grid technology and business models relate to existing systems and their lack of interoperability due to technical constraints and security, but also human factors and the modernization of working processes.

- Monitoring systems do not integrate and the different actors do not have the complete picture of the situation.
- Control is not coordinated making it impossible to manage complex problems such as DER integration or grid stability
- New players are excluded from existing business models and marketplaces, requiring regulatory development and harmonization, as well as platforms for information exchange.

Many of these barriers prohibit demand side flexibility to be utilized to its full potential.

To foster new business models and interoperability between systems, platforms and actors, open middleware architectures can play an important role as enabler. This will be discussed in the following together with the results and experience gained from the e-GOTHAM project.

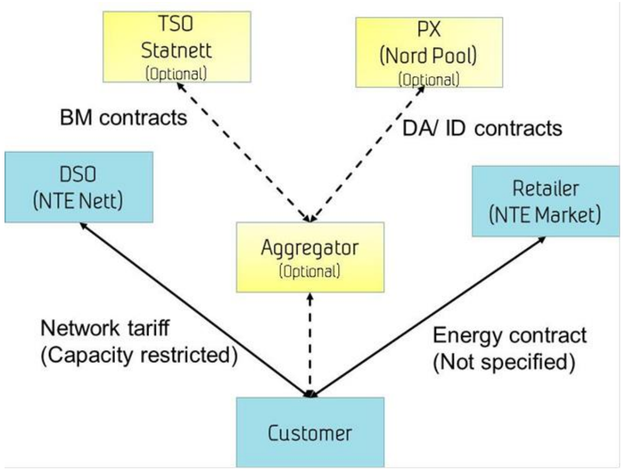

Figure 2: Stakeholders utilizing the same middleware through a multisided business architecture

SMART GRID MIDDLEWARE

As mentioned, an open middleware is a key component to enable interoperability and this is the most important characteristic for facilitating active distribution grids and active customers in the same multisided business architecture. This multisided business architecture is featured by a shared ICT platform (the smart grid middleware) connecting different stakeholders across the traditional value chain. This in turn introduces new players to the market, developing services and application on top of the middleware. DSOs, Retailers, customers and aggregators must all have restricted access to the same information and services through such a middleware (see Figure 2).

e-GOTHAM Architecture

The e-GOTHAM architecture aims at developing a middleware that enables the operation and support of multisided business models connecting DSOs, retailers, customers and aggregators together through tailored services and applications in addition to a semantic datamodel. The architecture supports integration of 3rd party devices as well as devices capable of embedding parts of the distributed middleware. All this, will support e-GOTHAM in implementing a new aggregated energy demand model in order to effectively integrate renewable energy resources, increase management efficiency by dynamically matching demand and supply. In addition, reduce carbon emissions by giving priority to green energy sources, raise energy consumption awareness by monitoring products and services and stimulate the development of a leading-edge market for energy-efficient technologies with new business models. The project has designed an open architecture and developed a middleware that enables the needed communications for management and results optimization. Figure 3 shows the developed conceptual architecture.

1 https://api.demosteinkjer.no/docs

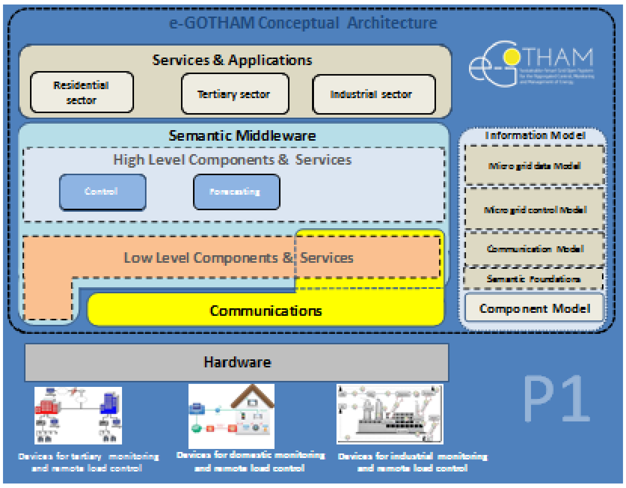

Figure 3: e-GOTHAM conceptual architecture

High level services

Typical high-level services/embedded applications in a smart grid MW stack will be:

- Forecasting (load, generation, market, weather)
- Optimization and decision support
- State estimation
- Commissioning tools
- Connectivity to external databases
- Business intelligence tools
- Customer dashboards

Demand-response operations towards both households and commercial/tertiary buildings are an important part of the microgrid optimization and verification of the ICT architecture. 5 commercial/tertiary buildings and 40 households are participating actively in the project.

Integration environment

The low-level services include in addition to communications, a set of tools for conversion and gateway-technology as well as the ability for distributed middleware architectures. This is where the message-oriented MW has its strong side, since a lot of the real time data analysis may be performed locally before storing to the central MW/database.

A lot of this functionality is included in the FUSE ESB/Apache servicemix bundles utilized in the project.

Communication architecture

The communication architecture is one of the most important aspects of a distributed middleware. A distributed system (as the grid with all its components) is tied together with the communication system. Thus, the communication architecture should be chosen carefully to ensure an efficient distributed system. e-GOTHAM has developed an AMQP-based communication protocol, with architecture as shown in Figure 4.

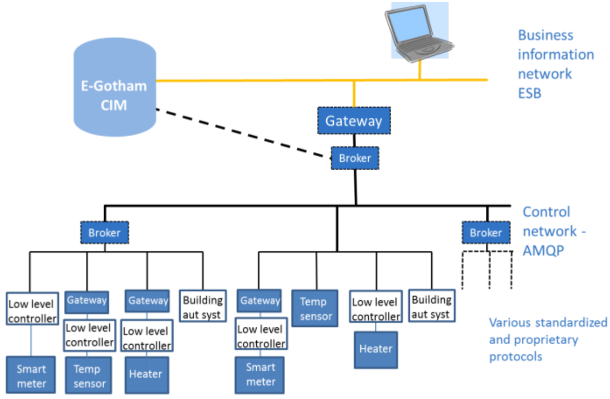

Figure 4: AMQP Communication Architecture

AMQP [6] is an Open standard application layer protocol for message-oriented middleware with built-in security features. It supports point-to-point, fan-out, publish/subscribe, and request/response. The chosen implementation is Apache Qpid, an open source implementation, maintained by the Apache Foundation.

The developed communication solution has interoperability mechanisms, scales very well (it is even used for home/building automation) and it seems to have sufficient real time properties. As part of interoperability mechanisms a Semantic Device Interface (SDI) is developed, to translate content of communication to a common information model. SDI is binary oriented and is based on CIM. This way of distributing the middleware supports using the same system for grid-related and customer-related communication and inter-domain/inter-actor functionality.

Middleware and databases

A semantic datamodel have been developed around a microgrid model, and all static data is stored using CIM. Dynamic data can either use CIM or IEC 60850. In addition all e-GOTHAM enabled devices (containing parts of the distributed middleware) also contain a real time database locally if necessary. Database connectors can easily be added or developed in order to connect to external databases. The Demo Steinkjer smart meter cloud database is one such example that is being interfaced with the MW.

Security architecture

AMQP supports transport security mechanisms and the architecture also supports role based routing mechanisms enabling lower layer security functionality. Higher level security mechanisms can easily be added as high level services in the MW.

DYNAMIC TARIFFS

The ICT platform plays an important role focusing on optimization of demand response through peak shaving.

Described testing of a new tariff is partly based on experiences from testing the "subscribed power" (or contracted capacity) tariff in Steinkjer and Hvaler in 2014 [4] . In total 48 customers participated in this test in Demo Steinkjer and Smart Energy Hvaler. The main purpose of this tariff was to equalize the consumption in peak hours and flexible load should be shifted in order to avoid peak hours for the customer. This tariff favors customers with low energy consumption independent from the use of power. But the introduction of advanced electric meters in year 2019 enables new opportunities of pricing programs for settlement and measurement of both energy and power consumption. The advanced electric meter is capable of measuring and recording usage data in time differentiated registers.

With capacity-based tariffs the customer needs information of the real-time power consumption and historical consumption hourly through a digital device.

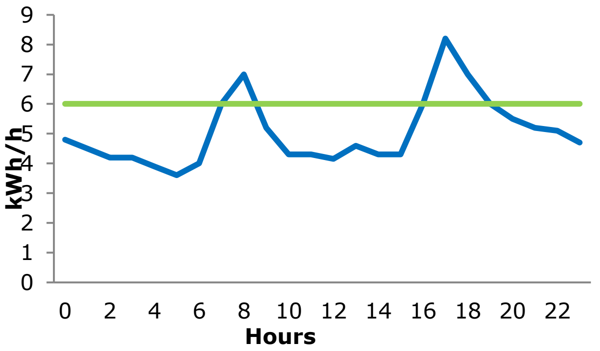

Figure 5: Contracted capacity as non-coordinated peak shaving

One of the weaknesses with such a tariff is that the tariff in [4] incentivize demand response even when not needed. In spite of this, such tariffs are preferred because of the easy operation and configuration, needing a minimum of ICT infrastructure.

The main limitation of contracted capacity is that the customer behavior is not coordinated with other customers, and thus the peak load will appear at the same time as before only somewhat reduced. In order to increase the degree of peak shaving, the DSM process must be coordinated and forecasted.

THE MICROGRID TARIFF

In e-GOTHAM, a new type of tariff, called microgrid tariff, is tested. This is a dynamic tariff that indicates congestions in the local grid, thus microgrid tariff as a first step to have an incentive to fix the situation in the local environment. One can also imagine this to be a first step towards more or less autonomous grid cells controlled by a hierarchy with an overall control strategy. These grid cells may also be called microgrids, thus the name of the tariff being tested.

The tariff settlement is based on a prognosis and a grid measurement. Only the customers that are expected to have grid constraints, will receive notification of a tariff increase. This is done in two steps:

1. Day ahead prognosis, estimate congestion and give a prewarning to the customers affected. The prognosis is updated until the hour ahead and changes might influence on the tariff
2. A grid measurement (in this case at the secondary substation level), verifies or cancels the expected peak load hours that is the basis for the increased price zones

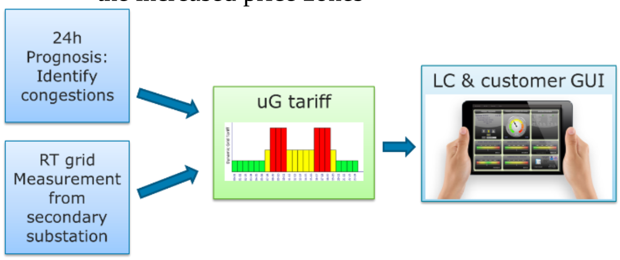

Figure 6: Microgrid tariff

The Microgrid Tariff details

There are four important concepts for the dynamic microgrid tariff:

1. The substation Load
2. The substation power limit – The utility decided power limit for the substation (the load should not exceed this limit for a long time)
3. The customer load – The customers actual consumption
4. The contracted capacity limit - The customer pays for the wanted and most reasonable power limit. The higher limit, the higher price.

Prices are high if and only if the load exceeds the Substation power limit AND the consumer consumption exceeds the contracted capacity limit.

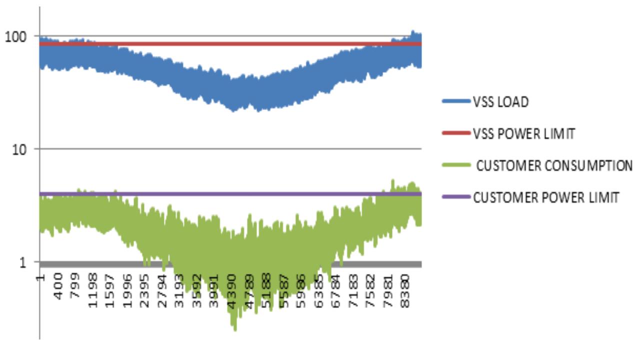

Figure 1 – Virtual substation (VSS) and customer power limits-real figures. The Y-axis unit is kW. The X-axis unit is hours, starting from January 1st.

The above picture shows the Substation and the contracted capacity (power) limits in the same picture with a logarithmic scale. In this example, the substation power limit is set to 85,5kW and in this case, the consumer pays for a contracted capacity limit of 4 kW. The testing utilizes a virtual substation where the thermal power limit is lower than the physical limit to reduce risk of outages during the testing.

The consumer will only pay the high tariff price when both loads are above each limit in the same hour. In this case, the customer would pay the high tariff price in 61 hours during a year. As one could notice, the congestions at the substation level strongly correlates with the seasons in Norway. The actual peak-shaving is done either by manually control carried out by the consumer (switch off) based on the information on the display, or automatically by the local e-Gotham equipment.

NEXT STEPS

The same infrastructure (Demo Steinkjer and MW) will be used in another EU-project called I3RES, where OPF and state estimation algorithms are implemented as MW services and contribute to an optimal grid operation involving the control (optimal set-point regulation) of a 2 MW hydro power plant.

DISCUSSION

Real time requirements and security issues are the major discussion points against MW solutions. At the same time such solutions are necessary to migrate from the traditional SCADA-way of gathering information to a future where structured and unstructured data must be combined using business intelligence and combinations.

The microgrid tariff has the ability to engage peak shaving where it occurs and when it occurs. If effective, the utility could benefit from:

- postponed grid investments
- optimized LCC for the components in the grid

The model is dependent of the quality of the prognosis, which consists of weather, historic and self-learning information. The tariff efficiency also depends of the consumer willingness to manually switch off load when needed. Another issue is the possibility to automatically curtail loads in such a way it will not affect the instant power quality.

CONCLUSIONS

An open and scalable smart grid middleware have proven valuable in order to establish a multiactor, multisided business architecture where operational requirements for grid operation and optimization can be realized as well as customer specific energy related services on the other side can benefit from the same infrastructure. The distributed middleware is one of the key components to enable this.

The microgrid tariff tested in Demo Steinkjer show how the ICT infrastructure enable the grid company to handle a dynamic situation with flexible tools giving the affected customers incentives to assist in coping with the grid challenges and moving towards integration of active customers and active distribution grid operation.

ACKNOWLEDGEMENTS

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