Demonstration environment for smart grid applications

Second version, 26.4.2011

Tampere University of Technology

Department of Electrical Energy Engineering

Authors: Antti Koto, Shengue Lu, Antti Rautiainen, Sami Repo and Turo Valavaara

REVISION HISTORY

Edition	Date	Status	Editor
1.0	30.9.2010	Version published in INCA project	Authors
2.0	26.04.2011	Fully working communication from ThereGate to SCADA, SGEM phase 1	Authors

ABSTRACT

A central idea of smart grid is to integrate all kind of active resources to the operation of electricity market and networks. The smart grid management may utilize these resources for multiple purposes and they may be located anywhere. The utilization of small-scale resources like load control of domestic devices is becoming possible and these resources are also needed in smart grid management. However the integration of small-scale resources to existing electricity network management system requires aggregation of information. The integrated information and automation systems are fulfilling the gap between small-scale resources and existing utility systems. Home energy management might be a gateway to multiple resources behind it and also a place for local decision making applications.

The ICT demonstration environment developed during the project and described here should be applicable for multiple smart grid applications. The profitability is strongly based on cost sharing between several applications. At the moment the demonstration environment have IT architecture, distribution network operator control centre software (ABB MicroSCADA Pro DMS 600), aggregator software (Open EMS Suite), OPC UA interface between SCADA and Open EMS Suite, home energy management (ThereGate), several measurements and active resources and an application of frequency dependent load shedding.

The development of demonstration environment is a moving target i.e. it will be always under development. The development work will continue instantly in Smart Grid and Energy Market program. Next connection point peak load reduction, monitoring of reserves and network overload management applications will be implemented and demonstrated. Other applications planned for next two years are smart home energy management (minimization of charging costs), low voltage network management and production following charging of electrical vehicle.

CONTENTS

ABBREVIATIONS

AMI	Advantage Metering Infrastructure
API	Application Program Interface
CIS	Customer Information System
CM	Configuration Management
DB	Database
DER	Distributed Energy Resources
DG	Distributed Generation
DMS	Distribution Management System
DNO	Distribution Network Operator
EV	Electric Vehicle
GUI	Graphic User Interface
HEM	Home Energy Management
HTTP	Hypertext Transfer Protocol
ICT	Information and Communication Technology
IT	Information Technology
LV	Low Voltage
MF	Mediation Framework
MOF	Managed Object Framework
MV	Medium Voltage
NE3S/WS	NE3S Web Service Common Interface
NIS	Network Information System
OCoS	Open Configuration Data Standard
OES	Open EMS Suite
OMeS	Open Measurement Standard
OPC DA	OPC Data Access
OPC UA	OPC Unified Architecture
OSS	Operation Support System
PM	Performance Management
Resource	Electrical equipment (generator, load, etc.) which may be controlled by aggregator or by home energy management
RTDB	Real-time database
SCADA	Supervisory Control and Data Acquisition
SCIL	Supervisory Control Implementation Language
SNMP	Simple Network Management Protocol
SOAP	Simple Object Access Protocol
SQL	Structured Query Language
TSO	Transmission System Operator
XML	eXtensible Markup Language

1 DEMONSTRATION ENVIRONMENT

1.1 ICT system

A central idea of smart grid is to integrate all kind of active resources to the operation of electricity market and networks. The smart grid management may utilize these resources for multiple purposes and they may be located anywhere. The utilization of small-scale resources through ICT systems integrating information and automation systems in several levels is becoming possible due to ICT development and cost reduction. However the most important is that the need for smart grid applications utilizing small-scale active resources is becoming evident. These needs are:

- Large-scale resources are already utilized or the cost of resources is extremely high
- Operation of electricity market and networks is becoming more challenging due to growth of uncontrollable power production and new type of loads
- New services are going to offered to customers
- New parties are entering to the electricity business
- New business models are adopted

The integration of information and automation systems is the key enabler of smart grid. Figure 1.1 represents an overview of information and automation systems fulfilling the gap between small-scale resources and existing utility systems. The utilization of small-scale resources in the upper level information systems requires aggregation of information. The aggregator is a centralized information source to existing utility systems. Aggregator should be extremely reliable and have high availability when critical smart grid management applications are utilizing its information. It is quite natural to think of aggregator as a sophisticated SCADA for small-scale resources.
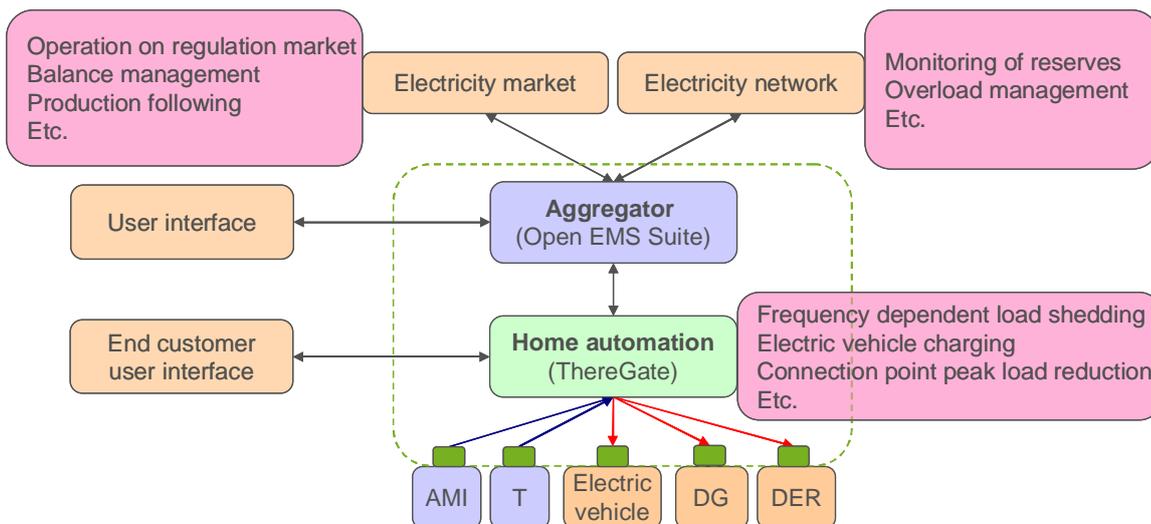

Figure 1.1. Hierarchical levels of information and automation systems.

The second part of new information and automation system is the home or building automation. This is a gateway to multiple resources behind it and also a place for local decision making applications. Application

examples are listed in the Figure 1.1. In order to communicate with a resource there is needed an interface at resource side. In practice this is probably the trickiest part of whole system because interface to existing resources requires tailoring. Home energy management is locally a centralized place for information. All measurements are collected to it and also decision making is mainly located there.

Communication between aggregator and home energy management is based on messages like XML files. In order to reduce the number of messages event based messages initiated by e.g. status change of resource should be exploited. The supervision of ICT system and resources requires also check queries in order to ensure the capability of "silent" system. Communication media could be anything and based on standard protocols like TCP/IP.

The ICT system described here should be applicable for multiple smart grid applications. The profitability is strongly based on cost sharing between several applications. Investment costs are too high compared to income from single application. Multiple applications may share almost the same cost than single application because the ICT system utilization time of single application is typically small and investment costs are much higher than operation costs. Because there is a need for a multipurpose ICT system very time critical applications like network protection functions are not supported by the system.

1.2 Electricity distribution network automation system

Figure 1.2 represents the automation system for electricity distribution network management. Traditionally information from different part of the system is gathered together to control centre where decisions about network operation are done by operators. The structure of centralized distribution network management is represented with dashed lines. The proposed system is based on distributed concept, represented with solid lines, which is capable of distributing intelligence, applications, and communications.

Distribution of intelligence and decision making is becoming possible due to addition of measurement and control devices into medium voltage (MV) and low voltage (LV) networks and also due to cheap and capable enough communication. In this way some duties of operators and some completely new tasks may be distributed to lower levels of automation system. At the same time the management of distribution network may be improved by speeding up the decision making and utilizing DER in distribution network management. This is very important in smart grids where very large number of measurement and control devices is available for network management. The role of operator is to supervise the functioning of these automatic systems.

Aggregation of information may be realized in many levels. Control centre is an obvious location to aggregate information and to make centralized complex decisions. However control centre does not need to know every detail of small scale resources located at customer sites at least in real time. If more detailed information is required, this information is available at lower levels of automation system.

Starting from the bottom the first level to aggregate information is home energy management (HEM) system which is managing DERs. It gets measurement data from DER, make decisions to operate them (e.g. minimize EV charging cost or maximize local usage of produced energy), realize network management commands from upper level automation systems (e.g. reduce power taken from distribution network in order to relieve network congestion) and send relevant aggregated information to upper level automation systems. MV/LV automation located at secondary substation is gathering information from HEM, smart meters, secondary substation measurement devices and IEDs. MV/LV automation is monitoring and managing

secondary substation and also LV network. Substation automation located at primary substation has been influenced a lot by IEC 61850 substation automation standard which enables interoperability of IEDs to introduce intelligent protection, monitoring and control functions.
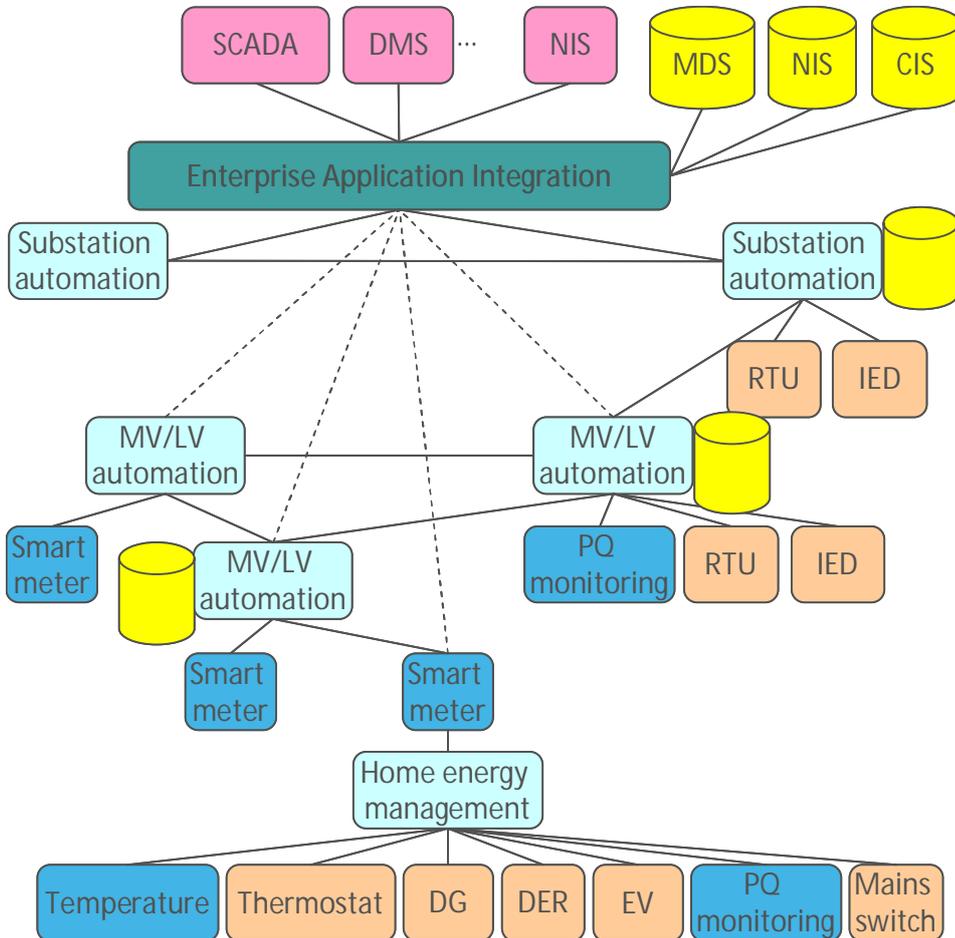

Figure 1.2 Electricity distribution network automation system.

1.3 Smart grid use cases

Here are described two use cases where above ICT and electricity distribution network automation systems could be utilized.

1.3.1 Monitoring of reserves

Power system reserves are controllable resources to balance system frequency and voltage in normal and disturbance conditions. Large-scale reserves from power plants, industrial loads and transmission system operator's (TSO's) own reserves are part of power system automatic control and protection system. The cost of automation system per resource is not a big question due to importance of reserves and small number of resources. Small-scale reserves are typically controllable loads like EV charging, space heating, hot water boilers, etc. which include some type of energy storage in order to minimize the discomfort for the customer.

The real-time supervision of reserves which is currently mandatory for large-scale reserves requires enormous investments on ICT system for small-scale resources. However many automatic reserves may be

operated based on local measurements like frequency or voltage which are measure of active and reactive power balance respectively. The operation of reserves does not require real time communication to TSO control centre. The system should be however designed so that the reliability of power system is not compromised (TSO's trust is important). The monitoring of reserves is needed to fulfil this obligation.

The proposed design of ICT system is based on facts which are true for large number of small-scale resources. When there exist large number of resources unavailability of single or even few resources is not critical from power system viewpoint. The capacity of resources could be forecasted by statistical methods quite accurately thus there is not need for real-time monitoring of reserves. The collection of measurement data from all resources may be slower and for statistical analysis purposes it might be done much later. Also the report from the disturbance situation and resource's actions should not be send until the disturbance is over.

TSO wide monitoring system should also have several hierarchical levels which are monitored with e.g. increasing delay towards the small-scale resources. For example TSO's SCADA get information from aggregator every 5 second. When the aggregator is utilizing a common ICT system with a distribution network company it get information e.g. from HV/MV substation automation system every 15 second which get information from LV network automation system every 30 second or when the capacity of resources has changed enough. Home energy management sends information to LV network automation every time when the status of resource is changed. Addition of hierarchical levels decreases the communication burden of servers but also increases the complexity of the system. Hierarchical system provides non-real-time monitoring data but also short- and long-term statistical forecast of resources. Statistical forecasting should be done at the level where information is accurate (real time) enough and statistical summation is smoothing out the effects of individual devices. Here it is assumed that this level is the aggregator.

In addition it is useful to know what kinds of reserves are available. This information may be get from aggregator database where contract details are stored. Reserves are classified as normal and disturbance reserves and also classification according to response time is used for disturbance reserves. Frequency dependent load shedding is also classified for different frequency thresholds thus the reserve capacity of each threshold should be known.

Following lists are examples of use case sequences related to monitoring of reserves.

Collection of resource information from home energy management

1. ThereGate collects and store to local memory instantaneous value measurement data and status information from meters, controlled devices, etc.

2. ThereGate updates mean and/or root-mean-square value of each measured value. Instantaneous values may be removed if they are not needed anymore.

3. Open EMS Suite (OES) agent at LV network management device request data from ThereGate, collects all reserve data belonging to same class and publish this data for next hierarchical level.

4. OES receives and identifies the message. Then the data is translated to XML used inside OES. Finally data is stored to database.

5. Check the quality of data.

6. Complement bad quality data points by queries.

Disturbance event of frequency dependent load shedding resources

1. Power quality guard measures frequency and send measurement data to ThereGate.

2. ThereGate shed contracted load if frequency is below a threshold value for under frequency load shedding.

3. ThereGate stores event data (timestamp, duration, type of control actions, amount of control actions and disturbance cause) and disturbance recording (instantaneous frequency)

4. OES agent at LV network management device request "Disturbance event" data and send it to OES. All messages should not be sent at same time in order to reduce jam in OES.

5. OES receives and identifies the message. Then the data is translated to XML used inside OES. Finally data is stored to database.

6. Check the quality of data.

7. Complement bad quality data points by queries.

Summary of real-time information about resources to SCADA

1. Collect real-time data from OES database.

2. Check the quality of data (queries from ThereGate are possible if there are missing, too old or outlier data in database, otherwise these should be removed)

3. Sum resources (powers)

4. Consideration of uncertain data (calculate the number of missing/rejected and bad quality data points, estimate the sum of missing/rejected and bad quality power from history)

5. Forecast near future sum of resources

6. Distribute aggregated data to SCADA via OPC-UA

7. Check if data has received and understood in SCADA (e.g. include confirmation request or "security key" for a message)

1.3.2 Network overload management

Currently distribution network overloading is avoided by maintaining appropriate network capacity for all probable network conditions. This requires over-investments and therefore utilization rate of network capacity is relatively low. The supervision of network loading is based on yearly statistical load flow calculations. Real-time supervision of network loading would make possible to increase the network utilization rate if the network overload management is available. Load control of small-scale resources would be an efficient way to postpone or replace network investments caused by occasional overloading.

The network overload management is needed because

- Over-investments are becoming more expensive by increased costs and by network regulation policy

- New type of loads like heat pumps and electric vehicles increase the loading of existing network

- LV network does not include monitoring and control at all

Centralized network overload management is a traditional control centre function implemented for example in DMS. Network overload management is based on real-time measurements from network, load flow calculation or state estimation of managed network and comparison of results to maximum loading values. DMS function gets real-time measurements via proposed ICT system from customer connection points and possible other points like secondary substations, etc. DMS state estimation calculates best possible estimate for network voltages and currents based on real-time measurements. If overloading of any component is found the reasoning for load control will be started. Finally control commands to control loads are sent to chosen control resources.

Centralized system requires huge amount of data flow from measurement points to control centre without real need to do that. If the reasoning of LV network overloading could be realized e.g. at secondary substation or the reasoning of MV network overloading realized at primary substation there is not need to send measurements to control centre. The analysis of network overloading may be easily distributed. Measurements are collected to decision making device which has capability to calculate state estimate for the area monitored. This requires replication of network data of monitored area to decision making device. In this way the reasoning of network overloading may be done much closer to measurement points and control resources.

An example of automation system for LV network overload management is presented in Figure 1.2. The system may control DERs by means of smart meters and HEM system. First the latest measurement data is gathered from different sources like HEM, smart meters, secondary substation measurements and IEDs to decision making device. Then the state estimation algorithm of radial networks is called to calculate currents and voltages in all parts of LV network. The calculation results of state estimation are compared to operational limits of secondary substation and LV network. If some limits are exceeded then the location of problem is find out, the location of controllable resources capable to solve the problem are looked for and finally the operational command e.g. to reduce power flow is send to controllable resources.

The location, availability, resource size, etc. information of controllable resources is managed by HEM system. HEM aggregates the control resource information and send real-time information about aggregated control resources to decision making device utilizing smart meter communication. The final decision of controls is made by HEM because customer may want to prioritize utilization of resources.

1.4 Laboratory demonstration environment

The laboratory demonstration environment includes both the information and automation systems and the consumer devices which are working as active resource. The ICT system consists of distribution network control centre software like SCADA and DMS (ABB MicroSCADA Pro DMS 600), aggregator (NSN's Open EMS Suite), home energy management (ThereGate) and interfaces between these. The first application for ThereGate has been implemented which is frequency dependent load shedding algorithm. Active resources available for demonstration are listed below and also described how they are used:

- Electricity network frequency measurement from MX-Electrix's power quality guard (currently measurements are read using PC having reading system, in future direct communication e.g. z wave, wireless m-bus, etc. will be used)

- Two Kamstrup 382Jx3 energy meters are measuring powers of connection point and solar cells (z wave communication)

- Available active resources are batteries (1 kWh), controllable loads (several kW), solar cell (13 kW)

- QEES switches which may be controlled on/off and read power measurement remotely (z wave communication)

- Everspring temperature measurement device (z wave communication)

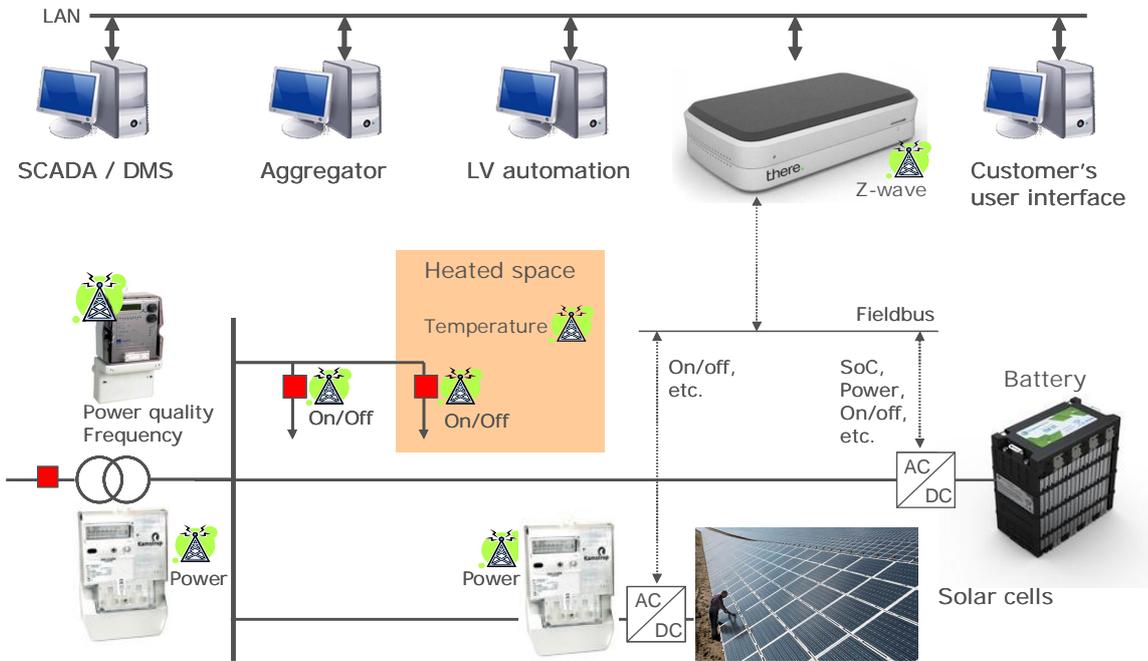- Insulated space (calorimeter) modelling a room heated by electric heating

Figure 1.3. Laboratory demonstration environment.

2 AGGREGATOR

Aggregator is a centralized information integration, storage and analysis tool for all kind of smart grid applications. It collects and stores to database all kind of operational information like control commands, queries, measurements, events, alarms, etc. The database includes also contract details, billing information and parameters of active resource controllers and applications.

Aggregating data

- Contracts of active resources

    o What is contracted (smart grid applications which may utilize resource)

    o With who (resource)

    o Period {for the time being, fixed}

    o Special conditions (if default parameter settings for smart grid applications are not applied)

- Contracts of smart grid applications

    o What is contracted (smart grid applications to which aggregator provides controllable resources)

    o With who (DNO, energy market participant, etc.)

    o Period {for the time being, fixed}

    o Default parameter settings for smart grid applications

- Storage of real-time measurement and status data

Collecting data

- Available resources

    o The state change of resource {on or off}

    o EV related information {starting / stopping of EV charging, estimated need for energy, charging current, wished time when battery should be fully charged, etc.}

    o Location of resource. Location could be a relation to customer's network connection point (this data comes from NIS) which has coordinates as an attribute. Also relation to customer information should be available for billing purposes.

- Real-time measurement data from each resource. Application defines what is collected:

    o Timestamp

- o Data {current, voltage, power, temperature, etc.},

- o Type of data {instantaneous value, mean value (+window size) or root-mean-square value (+window size) },

- o Trigger {time interval, event, change},

- o Trigger threshold {no threshold, 1 %, 10 %, etc.}, etc.

- Other data

  - o Temperature forecasts for each area

- Data from disturbance situations

  - o Event: timestamp, duration, type of control actions, amount of control actions and disturbance cause

  - o Disturbance recording: instantaneous value recording in COMTRADE format is stored for local memory / register for afterwards analysis

Sending data and commands

- Distribute a command from upper level systems and applications to resources

- Contract, tariff and spot market data for local automation devices like home energy management and EV charging point

- Setting parameters to applications in all levels

- Reporting

  - o available resources to upper level systems in real-time

  - o usage, value (money, reduced CO_2 emissions, etc.), etc. of resource to resource owner

- Special queries are also possible if needed to check if communication, automation and resources are available (alive).

2.1 Introduction of Open EMS Suite

Open EMS Suite (OES) is a software platform for developing operation support system (OSS) solutions. The OES architecture is based on the following key concepts: metadata driven applications make it possible to manage any services, networks, and network elements; fully integrated application functionality for fault management, performance management (PM), and configuration management (CM); easy to be extended and customised for customer needs. Therefore, we use OES as the aggregator in our project.

To make OES function as the aggregator, we follow these steps:

1. Modelling network resources. We define ThereGate and all its connected resources as element classes. In current laboratory setting, ThereGate is connected with only one type of resource - Switch. Therefore, there are two element classes in system, i.e., ThereGate and Switch. Each of them has some specific attributes. In addition, Theregate and Switch maintain a "Containment" hierarchy – i.e., each Theregate object contains one or more Switch objects. Figure 2.1 depicts ThereGate and Switch classes.

theregate
-Indoor_temperature
-TheregateID

1..1

1..*

switch
-resource ID
-status
-Timestamp
-Duration

Figure 2.1 ThereGate and Switch class

2. Making adaptations in OES SDK, and then deploying them to OES server. An adaptation consists of metadata provided by the OES customer to configure OES to the given models, networks, and protocols. When deploying, OES creates database tables according to these metadata. From application developers' standpoint, two adaptations are worthy of noting. One is CM adaptation, the other is PM adaptation. CM adaptation introduces a new model to OES. The model includes classes, attributes and relationships, as we have designed in step 1. Besides, CM adaptation specifies the structure details of Open Configuration Data Standard (OCoS) files that can be loaded into OES. After deployment, OES Managed Object Framework (MOF) is able to create, store and present managed objects of the specified class. PM adaptation defines measurement types. It also specifies the structure details of Open Measurement Standard (OMeS) files that can be loaded into OES. After deployment, OES PM Platform is able to store, process measurements of that type.

3. Implementing mediation components. A mediator is a software component that provides the necessary data conversions and protocol-level integration between lower-layer network elements and OES system, or between OES system and upper-level network management system. In our project, we need to implement two types of mediators. One is called Southbound mediator, for integrating Theregate and OES, The other is called Northbound mediator, for integrating OES and SCADA server.

4. Creating element instances. When element instances are created, specific element instance is mapped to specific element type. In practise, we can create ThereGate instances manually on OES desktop, with each ThereGate instance denoted by one ThereGate Object. Note that we cannot create Switch instances manually on OES desktop, because at the beginning we have no idea how many switches are connected with each ThereGate instance (and there is no need to know this). Instead, Switch instances should be later created automatically by loading OCoS files from Southbound mediator.

5. At this point, OES starts accepting data from element instances and keeps them in database. For CM data (i.e., network topology), OES MOF can visualize them on OES desktop. For PM data (i.e., measurement data), OES PM Platform can aggregate them and generate report.

OES was originally designed for managing a set of network device elements. Typically, these elements use SNMP (Simple Network Management Protocol) to communicate with management system. OES provides built-in support for integrating these types of elements. However, in our system, this is not the case. In our system, from OES point of view: the lower-layer network elements are ThereGate, which can only communicate with other management systems via HTTP; the upper-level management system is SCADA server, which can only communicate by using OPC protocol. Obviously, the crucial part of our task is to implement Southbound mediator and Northbound mediator, so that OES is able to exchange data with ThereGate and SCADA server.

2.2 System Architecture and Components

Figure 2.2 illustrates the system architecture of our Aggregator solution. ThereGate is controlling and measuring all kinds of electric devices like Switches. A piece of software called Agent is running on some computer, and it has Internet connections with both ThereGate and OES. Essentially, the agent functions as Southbound mediator. It uses Hypertext Transfer Protocol (HTTP) to fetch raw data from ThereGate and generates XML files accordingly. It then sends these XML files to Mediation Framework (MF) in OES by using Simple Object Access Protocol (SOAP). As a result, all the measurement data and network topology data are populated in database. Another piece of software called Northbound mediator, is located on some other computer. It has Internet connections with both OES server and SCADA server. It extracts aggregated measurement data from Database then sends to SCADA server by using OPC protocol. In the remainder of this section, we will go through the technical details of the agent and Northbound mediator implementations.
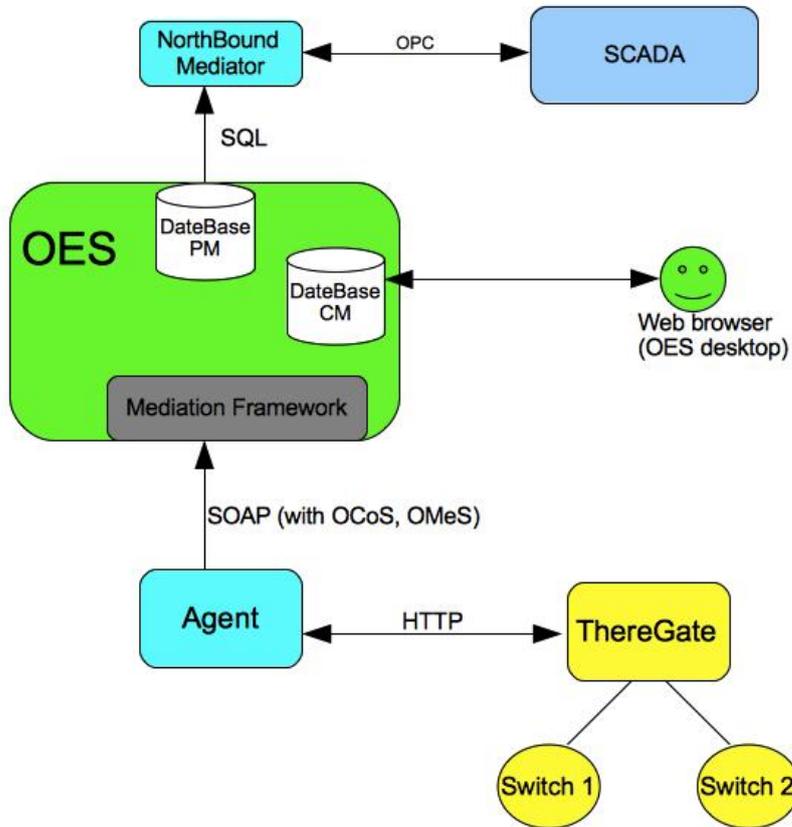
Figure 2.2. IT architecture of the aggregator.

2.2.1 The Agent: ThereGate and OES Integration

We implement an agent to integrate ThereGate with OES. Every minute, the agent retrieves real-time data from ThereGate, and then sends to OES Mediation Framework. As a result, all these real-time data are populated in database in OES server. The agent consists of three components: HTTP Client, OCoS/OMeS file generator, and NE3S/WS interface.

(1)   HTTP Client

The agent uses built-in HTTP Client to retrieve real-time data from ThereGate. Every minute, the agent issues HTTP GET request to ThereGate HTTP server, which returns data in HTTP response. The data, expressed in JSON (JavaScript Object Notation) format, contain updated value of TimeStamp, indoor temperature, power demand value, etc.

(2)   OCoS/OMeS file generator

The data retrieved from ThereGate are JSON format. However, OES can only accept input in XML format (i.e., OCoS, OMeS files). Therefore, the agent has to do some transformation work. In other words, the agent need to parse JSON file, extract some interesting information from it, then generate XML files.

The data extracted from JSON file can be divided into two types. One type is measurement data (PM data), which will be later handled by OES PM Platform to do aggregation calculation. We treat power demand value as PM data, and use it to generate OMeS file. The other type is network configuration data (CM data), which will be later handled by OES MOF and be presented on OES desktop. We treat Timestamp, Status, indoor-temperature, etc., as CM data, and use them to generate OCoS file.

One challenging issue about OCoS/OMeS file generation is how to make the generated files acceptable by OES server. As mentioned earlier, the acceptable format of OCoS/OMeS files are specified in CM/PM adaptations. Therefore, in our implementation, we first use OES SDK to generate example OCoS/OMeS files from CM/PM adaptations, then based on the example files our Java application creates correct OCoS/OMeS files on the fly. If later CM/PM adaptations are modified, then the Java implementation of the agent will have to be adjusted accordingly.

(3)   NE3S/WS interface

After OCoS/OMeS files are created, the agent should send them to OES server over the Internet. We implement NE3S/WS interface for this purpose: by using NE3S/WS protocol, the agent communicates with OES Mediation Framework (MF) and transmits OCoS/OMeS files to MF, and then MF takes care of the rest. In this way, the agent does not need to handle OES Southbound Interface details, and can be deployed in a very flexible manner.

Since NE3S/WS is based on Web Service technology, implementation of NE3S/WS interface means that the agent has to implement both Web Service and Web Service client. At the beginning, MF needs to discover and register the agent. During this stage, the agent functions as a Web Service, answering a series of SOAP requests from MF. After successful registration, the agent begins sending notifications to MF. During this stage, the agent performs as a Web Service client, sending SOAP requests to MF every minute. Its SOAP requests contain OCoS/OMeS files as attachment. We implement the Web Service and Web Service client by using Spring WS and Maven technology.

2.2.2   Northbound Mediator: OES and SCADA Integration

As shown in Figure 2.3, in our demonstration environment, there are several ThereGates, each of which is connected with one or more Switches. Each ThereGate is communicating with OES via an agent. The agent is polling the ThereGate every minute, so it can get updated power demand values of all the attached Switches from the ThereGate at every minute. The agent then writes these power demand values into OMeS files and sends to OES MF. As a result, the power demand value of every Switch in the system captured at every minute is stored in the Database of OES.
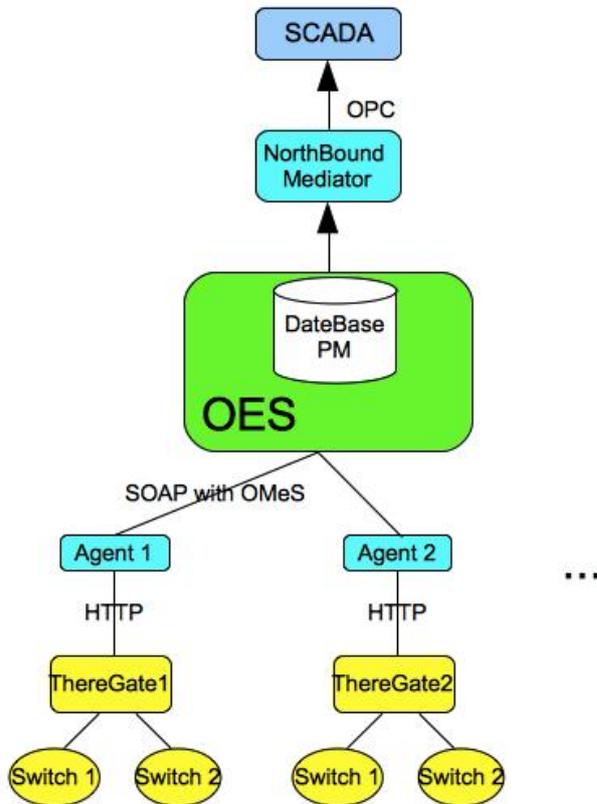
Figure 2.3 Aggregation of PM data

Our aggregation algorithm is: adding the power demand values of all these Switches together, and sending the sum to SCADA server at real-time. To this end, we implement a Northbound Mediator. At every minute, the Northbound Mediator generates/retrieves the sum from OES and sends to SCADA server via OPC protocol. Therefore, the granularity of "real-time" is one minute. We implement the Northbound Mediator by hacking an open source OPC client. Since the open source OPC client has already provided OPC protocol implementation, the only challenging issue we need to handle in the Northbound Mediator is retrieving the sum of power demand values from OES.

Define the Aggregation Algorithm in OES Adaptation

OES Adaptation SDK allows customers to define aggregation operations on PM data. In our Adaptation design, we specify power demand value as measured indicator, set the aggregation filter to All level in the network dimension, and set the aggregation rule to SUM in object direction. This configuration conducts OES to aggregate (i.e., perform mathematical addition) the power demand values of all these Switches together.

In OES Adaptation SDK, it is compulsory to specify aggregation rule in time direction. In our aggregation algorithm, we are not doing any operations towards power demand values on Time axis. Therefore, we

should specify the aggregation rule to NONE in time direction. Unfortunately, in current version of OES, if we set the aggregation rule to NONE in time direction, the Adaptation project cannot be deployed successfully. Our workaround solution is: set the aggregation filter to Minute level in the time dimension, and set the aggregation rule to SUM in time direction. This configuration conducts OES to aggregate the raw data to minute level at every minute. Since at every minute, the power demand value of each Switch in our system can only be polled once, this aggregation operation does not impose any influence on the raw data.

How to Retrieve Aggregation Result from OES?

Since we have defined our aggregation algorithm in OES Adaptation SDK, the issue that remains now is how to get these aggregation results from OES. There are three options.

- Northbound Mediation Interface (NMI)

    In practise, the Northbound Mediation Interface is some XML files in OES file system. Therefore, if choosing this option, the Northbound Mediator has to be located on OES server. The main problem with this option is: in current version, OES puts raw data rather than aggregation result in NMI. Therefore, this option does not work.

- PM Open Java API

    After defining aggregations and deploying the Adaptation, application developers can use PM Open Java API to generate report. The report contains the aggregation result. Therefore, we could get the aggregation result by using PM Open Java API to generate report in our Java application. However, this option has downside: this API is not very efficient when dealing with a bulk of raw data. Besides, for some specific aggregation algorithm which is difficult to define in the OES Adaptation, this API cannot do anything with it.

- PM SQL API

    This is a low, RDBMS-level interface, and because of this, it is more efficient. Furthermore, this API allows application developers to flexibly perform all kinds of aggregation operations towards raw data.

We choose the third option, i.e., PM SQL API, to implement the Northbound Mediator. In other words, we issue SQL statements via JDBC to manipulate aggregation operations directly through our Java application. One potential issue is: as more and more data are populated in the database table, the speed of the operation is getting slower and slower. However, we do not consider this issue at the moment.

2.3 Demonstration Environment and Testing Result

In order to evaluate our aggregator, we conduct some testing in laboratory. We perform two types of testing. The first type: OES is connected with two agents. None of the agents connects with real ThereGate. Instead, agents have built-in simulated Theregate that can generate random values. The other type: OES is connected with one agent. The agent connects with a real ThereGate.

2.3.1   OES Connected with Two Agents and Simulated ThereGates

The demonstration environment setting is depicted in Figure 2.4. There are two agents running on two different PCs. Each agent contains a built-in simulated ThereGate instead of connecting with a real one. The simulated ThereGate generates some random values every minute, as if there were a ThereGate attached with two Switches and those values were real-time "measurement data" collected from the two "Switches". This testing is only for illustrating the technical details of our aggregator.
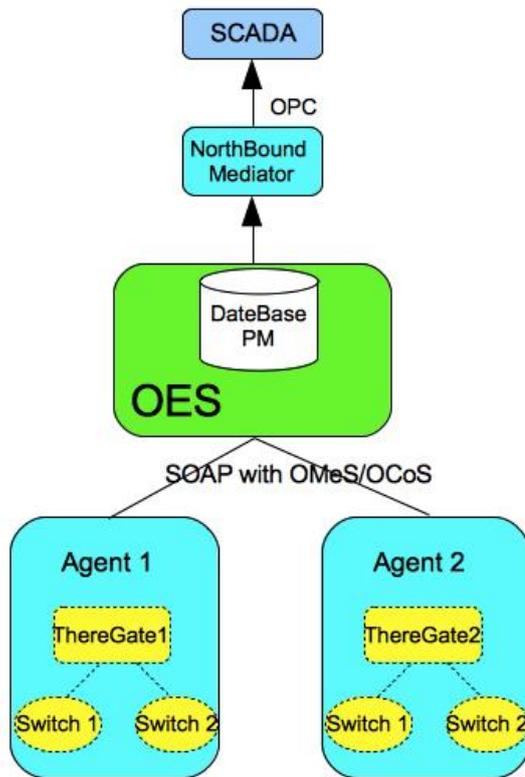

Figure 2.4 OES connected with two agents and simulated ThereGates

To start testing, we create two ThereGate instances on OES desktop, namely Theregate-1 and Theregate-2. After a while, agents start sending real-time data to OES on behalf of Theregates. CM data such as status, timestamp, indoor temperature, etc., are finally visible on OES desktop, as shown in Figure 2.5. (Note: the screenshot in Figure 2.5 is taken at a different round of testing. Therefore, its timestamp does not correspond

to those in the tables and screenshots at the remainder part of this section.)
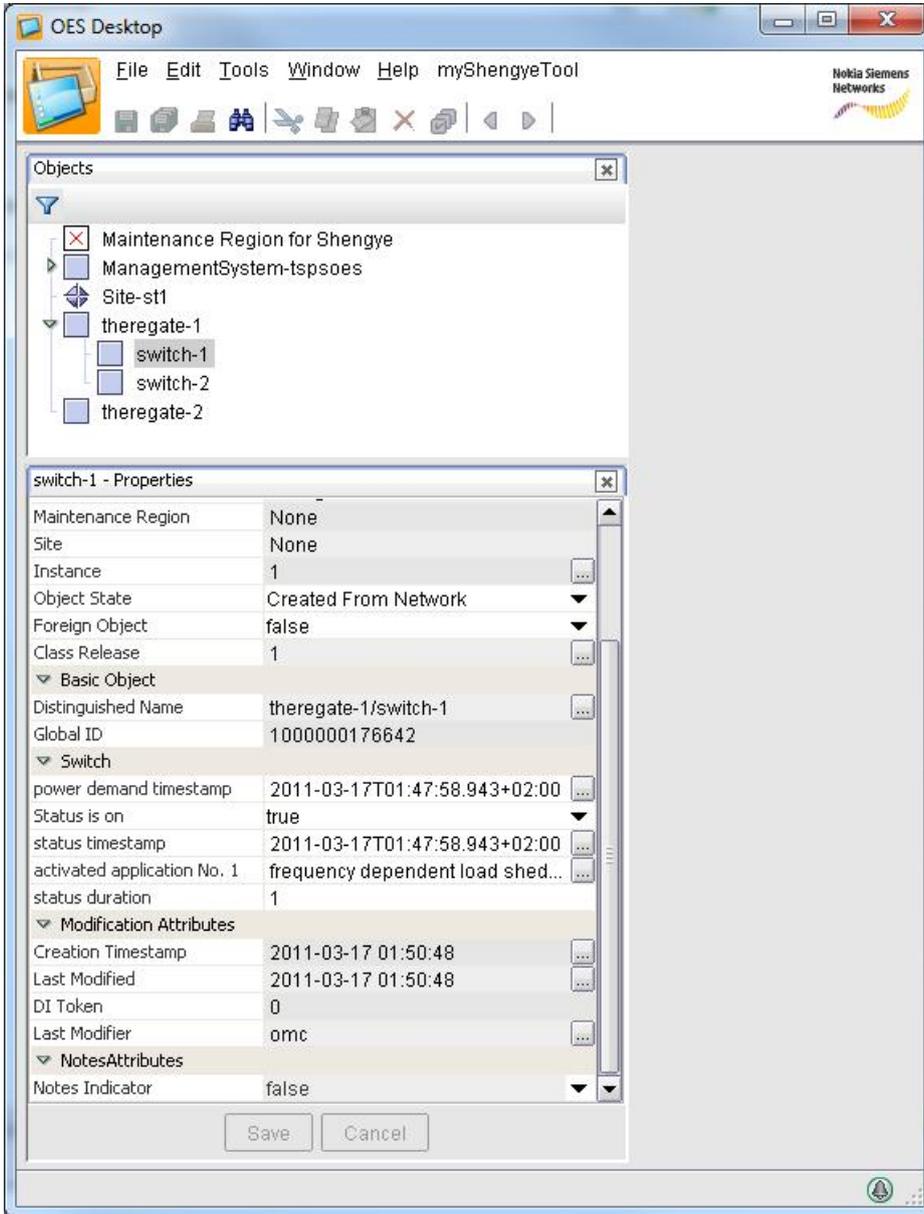

Figure 2.5 OES desktop with CM data received from ThereGate

In the meanwhile, PM data such as power demand value is populated in OES database. Table 2.1 is a copy of raw data in OES database. OES names the table as THERE_PMB.POWER_DEMAND. From the table, we can find:

(1) power demand values of the two switches attached with Theregate-1 are sent into database at every minute (at 13:XX:22) via one agent

(2) power demand values of the two switches attached with Theregate-2 are sent into database at every minute (at 13:XX:45) via another agent

Table 2.1 Raw data in OES database

NETWORK_ELEMENT	START_TIME	DURATION	POWER_DEMAND_VALUE
Theregate-1/switch-1	22/03/11 13:23:22.000000	60	.061730742
Theregate-1/switch-2	22/03/11 13:23:22.000000	60	.31286925
Theregate-2/switch-1	22/03/11 13:23:45.000000	60	.033319116
Theregate-2/switch-2	22/03/11 13:23:45.000000	60	.35985988
Theregate-1/switch-1	22/03/11 13:24:22.000000	60	.9077128
Theregate-1/switch-2	22/03/11 13:24:22.000000	60	.21834064
Theregate-2/switch-1	22/03/11 13:24:45.000000	60	.69830084
Theregate-2/switch-2	22/03/11 13:24:45.000000	60	.32065845
Theregate-1/switch-1	22/03/11 13:25:22.000000	60	.11194193
Theregate-1/switch-2	22/03/11 13:25:22.000000	60	.32903194
Theregate-2/switch-1	22/03/11 13:25:45.000000	60	.3429469
Theregate-2/switch-2	22/03/11 13:25:45.000000	60	.33734733
Theregate-1/switch-1	22/03/11 13:26:22.000000	60	.09694451
Theregate-1/switch-2	22/03/11 13:26:22.000000	60	.6443786
Theregate-2/switch-1	22/03/11 13:26:45.000000	60	.40894067
Theregate-2/switch-2	22/03/11 13:26:45.000000	60	.5078975

At the same time, Northbound Mediator is using PM SQL API to aggregate raw data directly and sending the sum to SCADA server at every 30s. Table 2.2 lists at what time and what exact value Northbound Mediator is sending to SCADA server. This table is created according to the debugging information from Northbound Mediator implementation for the sake of clarification. From the table, we can find: At 13:23:34 and 13:24:04, Northbound Mediator sends value 1.78521345kW to SCADA. This value is historical data in database, from last round of testing. Since it is not related with this run of testing, we can ignore it; At 13:24:34 and 13:25:04, Northbound Mediator sends value .767778988kW. This is the sum of power demand values collected from all these four switches during 13:23; At 13:25:34 and 13:26:04, it sends value 2.14501273kW. This is the sum of power demand values collected from all these switches during 13:24; ...

Table 2.2 Details of Northbound Mediator's sending data to SCADA

Sent Time	Value (kW)	Timestamp
13:23:34	1.78521345	2011-03-22 12:53
13:24:04	1.78521345	2011-03-22 12:53

13:24:34	.767778988	2011-03-22 13:23
13:25:04	.767778988	2011-03-22 13:23
13:25:34	2.14501273	2011-03-22 13:24
13:26:04	2.14501273	2011-03-22 13:24
13:26:34	1.1212681	2011-03-22 13:25
13:27:04	1.1212681	2011-03-22 13:25
13:27:34	1.65816128	2011-03-22 13:26
13:28:04	1.65816128	2011-03-22 13:26

The result of Northbound Mediator's work is immediately visible on SCADA server display. Figure 2.6 is screen shot on SCADA server.
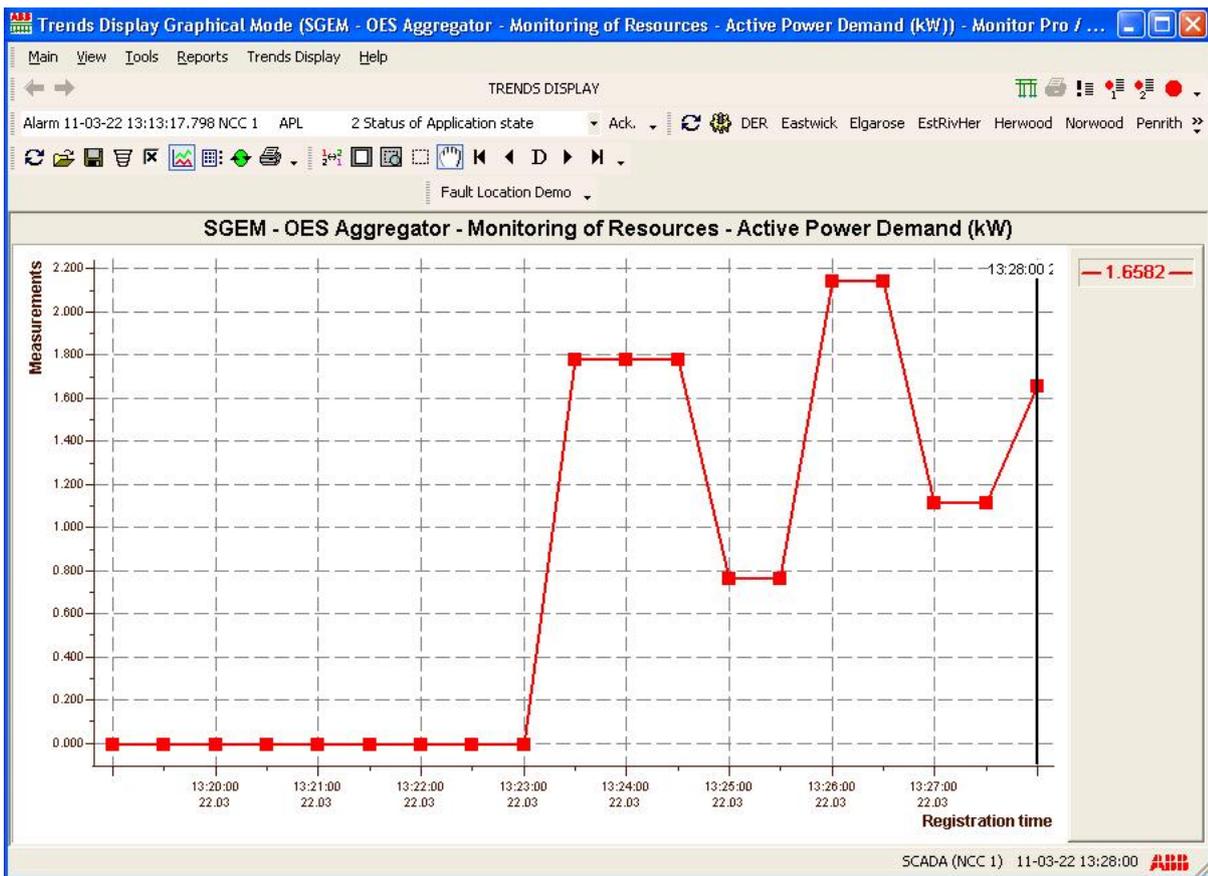

Figure 2.6 Screen shot on SCADA server

2.3.2 OES Connected with One Agent and One Real ThereGate

In the second type of testing, OES connects with only one agent. The agent is connected with a real ThereGate. Every minute, the agent sends to OES the real measurement data on behalf of the ThereGate. Figure 2.7 depicts the demonstration environment setting. The purpose of this testing is to give readers a real-world demonstration result of our aggregation solution.
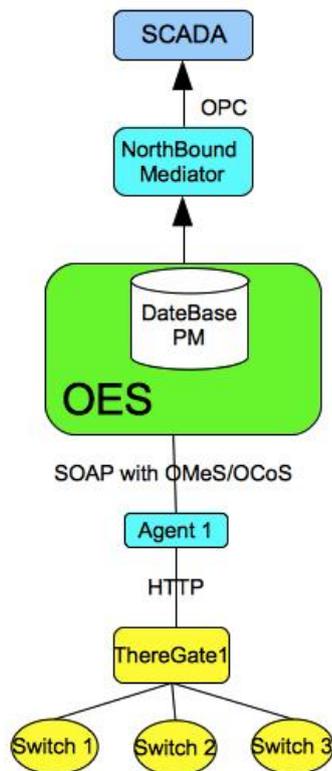

Figure 2.7 OES connected with one agent and a real ThereGate

As shown in Figure 2.7, ThereGate is attached with three Switches. Switch 1 is always off, so its power demand value is always 0. During the testing, we change the status of Switch 2 and Switch 3. At first, only Switch 2 is on. Then we turn on Switch 3. And finally, both Switch 2 and Switch 3 are turned off. Figure 2.8 is the screenshot on SCADA server display.
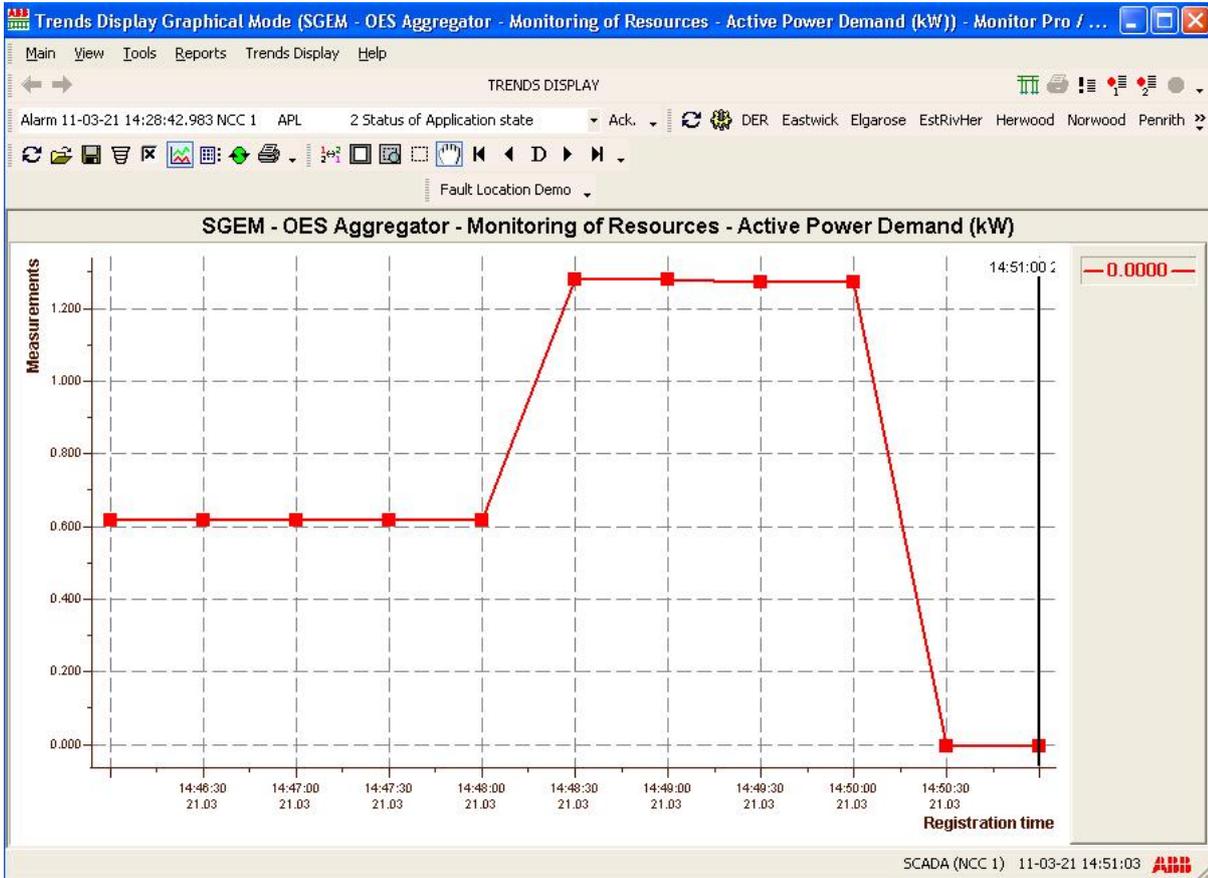
Figure 2.8 Screen shot on SCADA server

3 HOME ENERGY MANAGEMENT

Home energy management extends smart grid inside a customer's premises. It makes possible all kind of monitoring, demand response and other control functions needed for smart grid. Similar ideas have been presented for smart meters which might monitor connection point electrical characteristics and control dedicated loads. Home energy management is generally more flexible than smart meters because they may monitor and control different kind of devices including smart meters, embedding of new applications is straightforward, they include better data processing and storing capabilities and communication to other systems is based on common standards.

3.1 ThereGate

ThereGate, developed by There Corporation, is a home energy management control unit and a wireless router in the same package. Basically it is an advanced wireless router with integrated GSM/GPRS/3G and Z-Wave technologies. It also has a possibility to use batteries as a backup power. ThereGate runs on OpenWRT open source Linux platform and its aim is to be a technology independent platform for different smart home technologies. Currently ThereGate supports Z-Wave technology with its integrated Z-Wave chip, and M-Bus technology with additional USB technology adapter. Z-Wave is the only supported wireless technology at the moment. During 2011 There Corporation is developing drivers and support for at least ZigBee technology.

There Corporation aims to provide ThereGate with Web and Mobile user interfaces for ThereGate. These user interfaces are designed for the end user and are not very useful when thinking about smart grid applications. Currently only Web user interface is implemented and it allows user to add, monitor and control different devices. Supported devices include at the moment for example thermometer and humidity sensor (Everspring), motion detector (Everspring), switches/relays that include energy monitoring (QEES), electricity meters that support Z-Wave or M-Bus (Kamstrup) and so on. Web user interface also allows user to configure the WLAN router settings.

The Web UI of ThereGate uses HTTP-API (Application Program Interface) presentation bridge to communicate with ThereGate. This HTTPS-based communication can also be used to communicate with other software and applications, not only the user interfaces. It allows to execute methods of applications running on ThereGate, and so it can be used to get information from ThereGate and also to control devices and applications. Communication with ThereGate uses HTTPS-protocol to offer security and requires username/password -authentication from the user or application communicating. Downside of this communication architecture is that application or user has to make a request to ThereGate in order to get information as response, and at the moment ThereGate can't spontaneously send messages when for example some value changes enough or when some disturbance occurs.

3.2 Smart Grid applications at ThereGate

ThereGate can realize different types of smart grid applications based on local measurements and information. Two examples of these are mentioned in Figure 1. These are frequency dependent load

shedding and connection point peak load reduction. The first one has already been finished and the second application is under development at the moment.

3.2.1 Frequency dependent load shedding

Frequency of the voltage of the power system works as in indicator of the balance between power production and consumption. Frequency decreases if the total power production in energy conversion processes of power plants is less than total energy consumption in the system. And vice versa: in the case of power surplus frequency rises. Today frequency is used to adjust production of power plants in order to maintain the balance between power production and consumption. In Nordic power system this automatic frequency based adjustment is made in two different phases. When frequency is between 49.9...50.1 Hz frequency controlled normal operation reserve operates to maintain the frequency at appropriate interval. If frequency decreases below 49.9 Hz frequency controlled disturbance reserve capacity starts to activate and when frequency decreases to a value of 49.5 Hz all the capacity is activated. Some big industrial loads are also used as frequency controlled disturbance reserve being disconnected from the grid during a disturbance. The Finnish TSO has made some agreements with industrial companies to allow this kind of an action. In addition to automatic frequency control actions, resources of the regulation power market are very important for maintaining the grid frequency at appropriate level. Regulation power market is used by TSOs to control frequency level to free some automatic frequency regulation capacity.

In addition to large industrial loads, a great amount of small domestic loads could technically be used as frequency controlled reserve. Loads can be controlled based on local frequency measurements, and loads can be controlled in accordance of frequency in many ways. Some concepts and results concerning for example refrigerators (Short et al. 2007), space heaters (Rautiainen et al. 2009a) and electric vehicles (Rautiainen et al. 2009b) are available.

ThereGate could be used to control different loads in accordance of frequency. Local frequency can be measured from the network, and different loads can be controlled adjusting the setting values of thermostats of thermal loads or directly disconnecting loads from or connecting loads to electricity network. In some cases, as presented for example in Rautiainen et al. 2009b, it is possible to adjust the power of a load in continuous manner. If electric vehicle is capable of feeding energy to the grid, it is possible to start feed power and adjust feeding power in accordance of frequency. Currently there is no supported method to get the frequency measurement to ThereGate, but there is an ongoing project where the aim is to integrate MX Electrix Laatuvahti device with ThereGate for providing this information.

Figure 3.1 presents an example of a simplified cyclic algorithm describing the control principles in frequency dependent load shedding. The algorithm describes only the physical control actions, and does not include resource state monitoring, event registering etc.
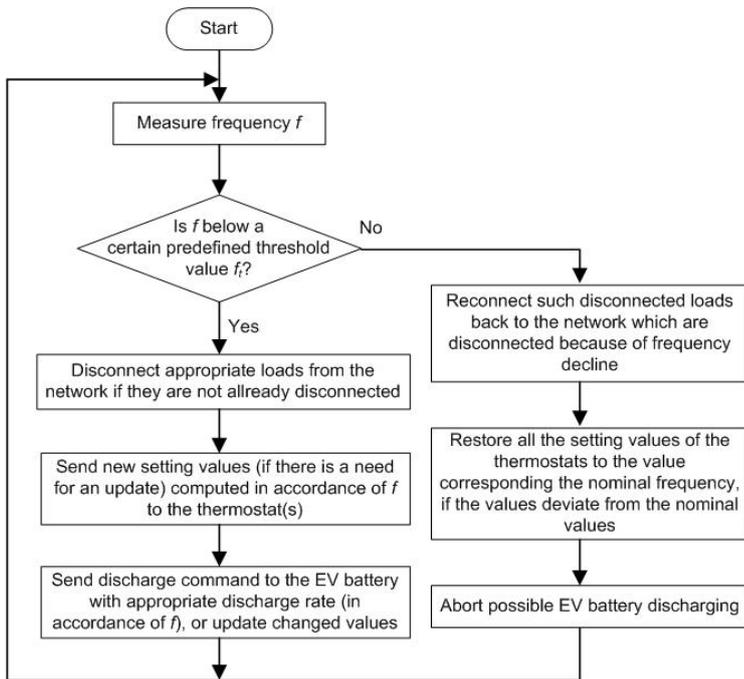
Figure 3.1. Cyclic algorithm of the control actions in the frequency dependent load shedding scheme.

3.2.2 Connection point peak load reduction

Customer electricity grid connections have a limited current capacity. If "semi fast" three-phase electric vehicle charging is used with a regular domestic connection, the maximum current capacity can be exceeded. The capacity of the network connection can be enhanced by enlarging the rating of the main fuses, but this increases the costs of the customer. Also, if this is applied broadly, it can lead to extra network enforcement investments and hence to an increase in transfer tariffs. In addition to limited current capacity, a possible application of demand tariffs in electricity distribution may offer incentives to restrict the peak load of a network connection.

It might be therefore attractive to increase the control of local loads to avoid remarkable increase of peak power. Today, it is common that electric sauna stoves, space heaters and storage water heaters are used in alternation mode (ABB). This means that if for example a sauna stove is switched on, space heaters are automatically switched off. This kind of an alternating system could be extended and applied to charging of a vehicle.

There are many possible operation principles for realizing this kind of a system. Figure 3.2 presents a principle of peak load reduction, in which some big loads are switched off and on to manage the peak power. Another feature could be current adjustment of some loads such as a plug-in vehicle charger. This means, that in addition to on/off switching of charger, the current taken by the charger could be adjusted discretely or "continuously". In these methods, it is important that indoor temperature does not decrease to a level too low when the heaters are switched off. This might happen in some circumstances during cold weather. Coordination of local loads could be further enhanced by incorporating local temperature measurements in the control method to ensure proper temperatures in the rooms. One possible control principle which does not take possible temperature decrease into account could be as follows. When semi fast vehicle charging is switched on, heating is switched off, and if a sauna stove is switched on, the charger is also switched off.

Another algorithm is presented in Figure 3.3. In this algorithm, there are two possible charging rates: semi fast and slow. Semi fast charging rate could correspond to approximately 10 kW power (three phases) and slow charging could correspond to 2...3 kW power. This algorithm takes indoor temperature decline into account when semi fast charging is applied. If electric sauna stove is on, it is assumed that the heat produced by the stove subsides part of the heat which would be produced by disconnected space heaters if they were not disconnected.
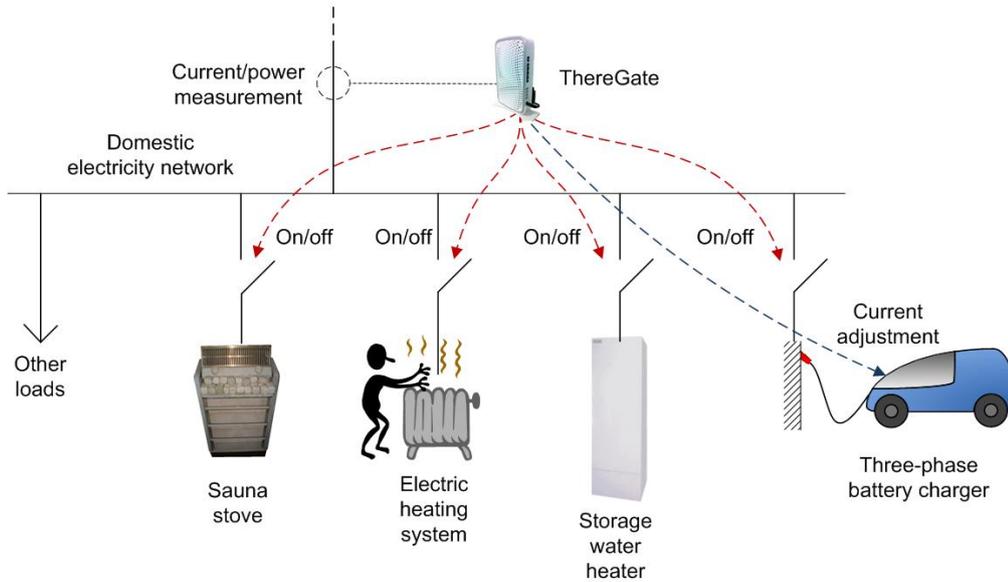

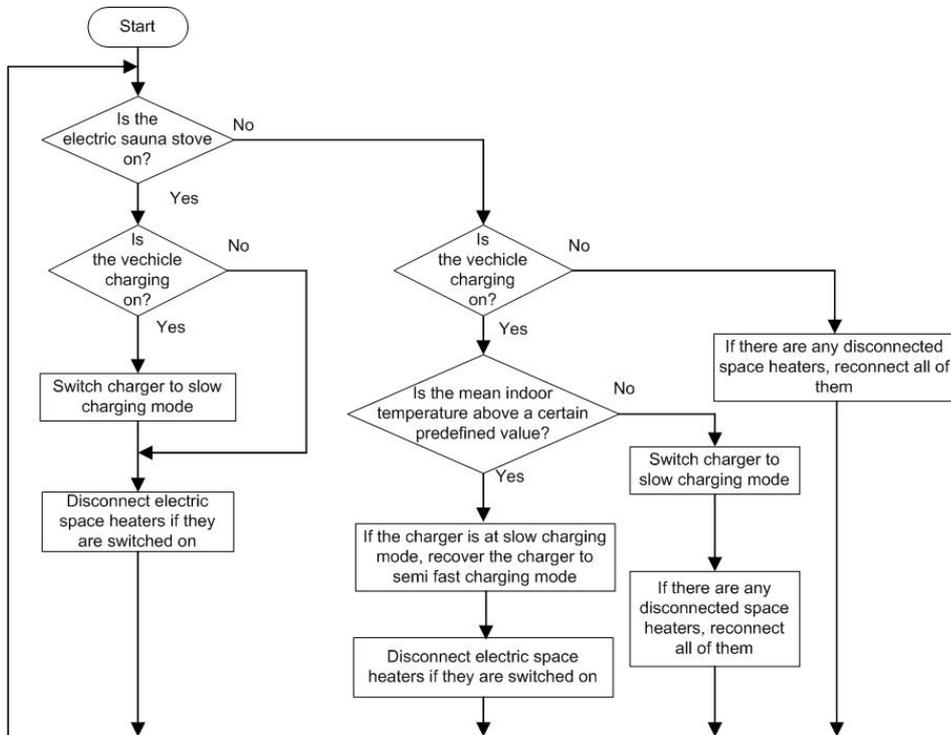Figure 3.2. Principle of peak load reduction system.

Figure 3.3. Cyclic algorithm of the control actions in the peak load reduction scheme.

Another way to restrict peak power is to share the capacity of the network connection for different loads in a pulse-like manner. Power could be delivered to each of the three loads in pulses, whose lengths can be adjusted with different criteria. In this approach, energy is delivered to each load one after the other and the energy needs of every load could be met to some extent. It is possible to measure the total current or power of an electricity connection, as presented in Figure 3.2 and use the "free capacity" which is available. Another option is to reserve a certain constant capacity which is shared between loads.

3.2.3   Examples

Currently there are three applications developed for ThereGate for demonstration purposes. One is very simple application that can be used to manually enter a value that presents grid frequency measurement (real grid frequency measurement is not yet integrated to system). It saves the frequency as a variable, and other applications can be set to listen changes in this variable and to react to those changes. This is to be placed with Laatuvahti frequency measurement, when the integration project is ready.

The second application is a thermostat. There was currently no suitable thermostat Z-Wave device, so we implemented a software thermostat using thermometer and a switch that are both controlled with Z-Wave. This solution has worked well in demonstration purposes. In real applications a factory-made Zigbee or Z-Wave thermostat would be used.

Third application is control application for frequency dependent load shedding. When initialized, it searches all controllable resources available. Then it listens to grid frequency value and when frequency drops under certain value, it first lowers the setpoint of thermostat and after that starts to disconnect available loads. When the grid frequency rises again, disconnected loads are connected and setpoint is set to its initial value. Current state of demonstration includes a couple of resistances as loads and a heater unit that is controlled with the thermostat. Distributed generation and EV should be added to the demonstration in the future. For the demonstration purposes a battery system is used to present the EV. Integration of the battery system will be done after finishing the fourth application.

Fourth application is customer connection point peak load reduction application. As explained above, the aim of this application is to prevent overloading of the customer connection point by making sure that there are not too many loads, like EV charging, sauna stove and heating, connected simultaneously. Currently this application is under development and is the next thing that will be implemented on the demonstration environment.

4 INTEGRATION OF INFORMATION AND AUTOMATION SYSTEMS

The demonstration environment consists of three components. These are home energy management device called ThereGate developed by There corporation, element management system called Open EMS Suite developed by Nokia Siemens Networks and electricity distribution network SCADA/DMS (Supervisory Control and Data Acquisition / Distribution Management System) systems called MicroSCADA Pro SYS 600 and MicroSCADA Pro DMS 600 developed by ABB Oy.

In the first version of the demonstration environment, these systems will be integrated with 3 interfaces which are set between DMS & SCADA, SCADA & OES and OES & ThereGate. The interface between DMS & SCADA is already in place and functioning as both systems are developed by ABB and designed to be used together. The interfaces between SCADA & OES and OES & ThereGate have been developed during the first phase of SGEM project.

4.1 Integration principles

In the demonstration environment there are three basic principles used in system integration. First, the amount of data transferred between systems has to be minimized. In demonstration environment high amount of data would cause no problems because there is only one ThereGate device connected to OES via local area network. However, in real environment the amount of data transferred is critical because the number of ThereGate devices can be significantly greater (one device for every household) and the data transfer capacity between OES and ThereGate devices might be limited.

The amount of transferred data can be reduced by using asynchronous publish/subscribe message exchange pattern. In publish/subscribe pattern clients (in this case OES) subscribe to certain data items they find interesting, and the server (ThereGate) sends data to client only when there is big enough change in the data values. In addition, the messages are designed so that they include updated data from all applications included in a ThereGate device. The objective is to reduce both size and amount of data packets.

Second design principle is to make use of the existing data transfer interfaces implemented in the SCADA, OES and ThereGate systems as much as possible. This will reduce the need for custom code and therefore speed up the development work. This is also the only option with most of the systems since they are closed source systems i.e. the source code of the systems is not available.

Third principle is to use platform independent data transfer solutions as much as possible. This design principle makes it possible to communicate with systems which operate in different environments using different operating systems and hardware. This is useful feature if there is need to add new information systems to the demonstration environment in the future.

4.2 Data exchange

Diversity of possible applications to be realized with ThereGate creates numerous variations of possible messages transferred between the systems. In this chapter a provisional list of different message types and an

example message is presented. These messages will be implemented one by one in phases 2 and 3 of the SGEM project. The messages are based on different kind of schemas describing the required and possible format of different kind of messages.

4.2.1 List of messages

Messages to OES from ThereGate:

- Disturbance event (real-time data)

- Disturbance recording

- Monitoring of resources (real-time data)

- Statistics of resources

- EV started charging (real-time data)

- EV stopped charging (real-time data)

- Registration of new resource

- Customer query about its own resource

Messages to OES from SCADA:

- Query to check if communication system is alive

Messages to OES from external information system:

- Addition of new contract or resource into aggregator system

Messages from OES to SCADA:

- Disturbance report to SCADA

- Summary of real-time information about resources to SCADA

- Query to check if communication system is alive

Messages from OES to ThereGate:

- Parameter change

- Query to check if communication and automation system are alive

- Distribution of contract and tariff data to resources

- Query of missing or bad quality data

4.2.2 Example message

The idea of message is that all information needed to report at same time is included into a same message in order to reduce the number of messages. In practice the message includes common part (explains what is reported etc.) and resource information part about real-time data of all resourced needed to report on that time. The example case of monitoring of resources message transferred from ThereGate to OES is illustrated below.

Common for all messages

- ThereGate ID

- Timestamp of message

- Measurement data (common for all resources):

    o Indoor temperature [°C]

Monitoring of resources (real-time data)

Resource data:

- Resource ID

- Status {on/off}

- Timestamp of status information (when information was updated) [UTC]

- Measurement data (depends what is available):

    o Active power demand / production [kW]

    o Reactive power inductive / capacitive [kVar]

    o Voltage [V]

    o Current [A]

4.3 Data integration

4.3.1 DMS – SCADA – Open EMS Suite

Data transfer between DMS and SCADA is realized with OPC Data Access (OPC DA) and OPC Alarms & Events (OPC A&E) interfaces. These interfaces are in-built in the systems. The OPC servers are located in SCADA and OPC clients in DMS. There is also possibility to use SCIL API interface between the systems. SCIL (Supervisory Control Implementation Language) is a programming language developed by ABB.

In data transfer between SCADA and OES the in-built interfaces of both systems are used. In SCADA this means OPC DA server and in OES we use Structured Query Language (SQL) to fetch data from OES database. Other data transfer possibilities for OES have also been studied but due to technical difficulties those were not chosen. These discarded technologies include XML files and Enterprise JavaBeans (EJB).

With XML files the problem was to get aggregated data (not raw data) into the XML files that were automatically generated by OES. The other alternative, EJB, was too complex technology for our needs.

To make the interfaces between OES and SCADA compatible with each other, separate software adapter between the systems was required. Furthermore, OPC DA technology is based on Microsoft DCOM and therefore doesn't support other operating systems than Microsoft Windows. As OES operates on Linux, this caused another problem which was solved by introducing platform independent OPC Unified Architecture (OPC UA) interface. OPC UA wrapper is used to present OPC DA server as platform independent OPC UA server. The software adapter between the systems is coded in Java and it provides the necessary data transformations between SQL and OPC UA. Towards SCADA the agent operates as an OPC UA client. Components used in data transfer between OES and SCADA are shown in Figure 4.1.
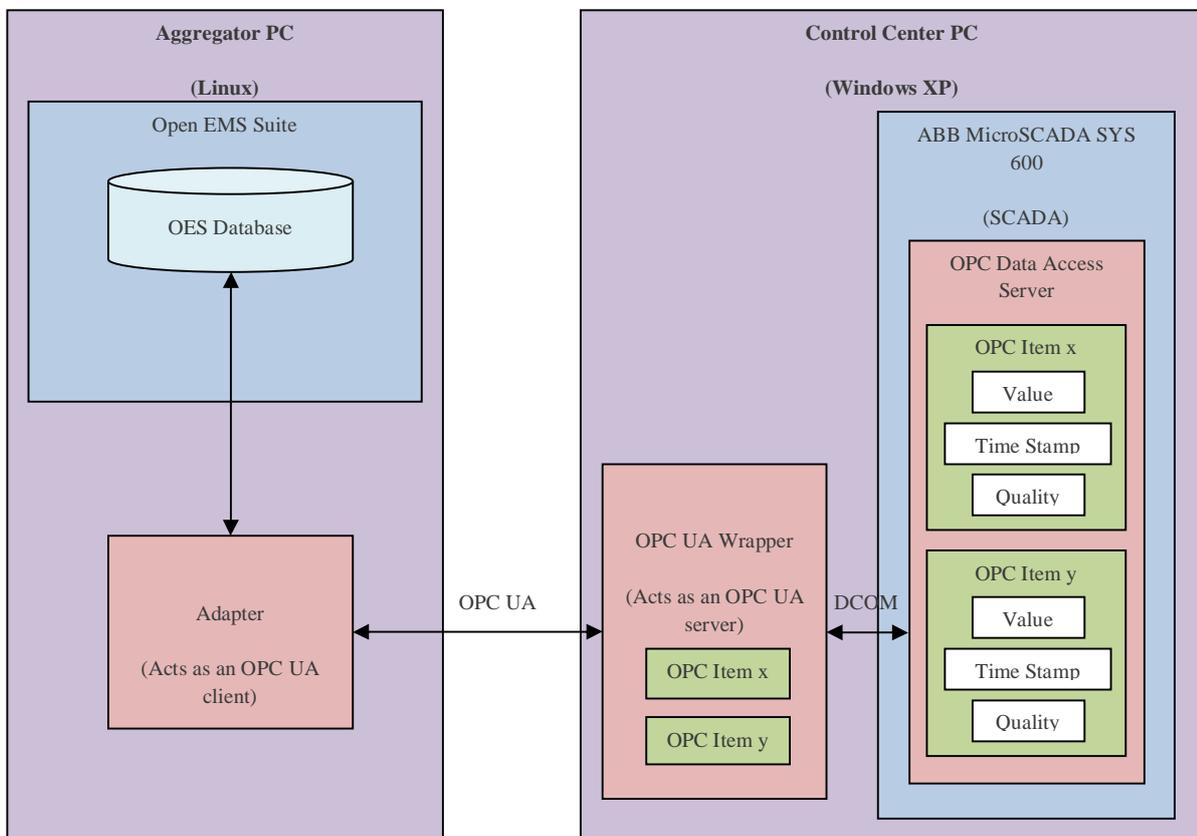

Figure 4.1. Integration of OES and SCADA.

4.3.2   Open EMS Suite – ThereGate

The integration of OES and ThereGate is realized with XML files on OES side and HTTP API in ThereGate. This interface also requires implementation of a separate software agent to provide necessary data transformations and publish/subscribe message exchange behaviour. The agent is a Java application which communicates to OES using SOAP (Simple Object Access Protocol) and to ThereGate using HTTP queries. SOAP is the data transfer protocol used in platform-independent Web Services and it is based on HTTP and XML technologies.

The agent can read XML files and transfer e.g. new parameter values to ThereGate device via HTTP API. The real-time data from ThereGate is queried by the agent once every 30 seconds. The agent then analyzes the received data and decides if there is need to update any values to OES via XML files. This means that between the OES and the agent publish/subscribe pattern is used and between the agent and ThereGate request/reply pattern is used. In the demonstration environment the agent is located in its own computer. The idea behind this is that later in real environment there could be a separate computer in LV network that could accommodate hundreds of agents and gather data from multiple ThereGates in centralized manner. For each ThereGate device there would be one agent. This kind of structure also means that there is a need for small local database in each agent. The same architecture is also suitable for LV network management. The architecture of the communication components is shown in Figure 4.2.
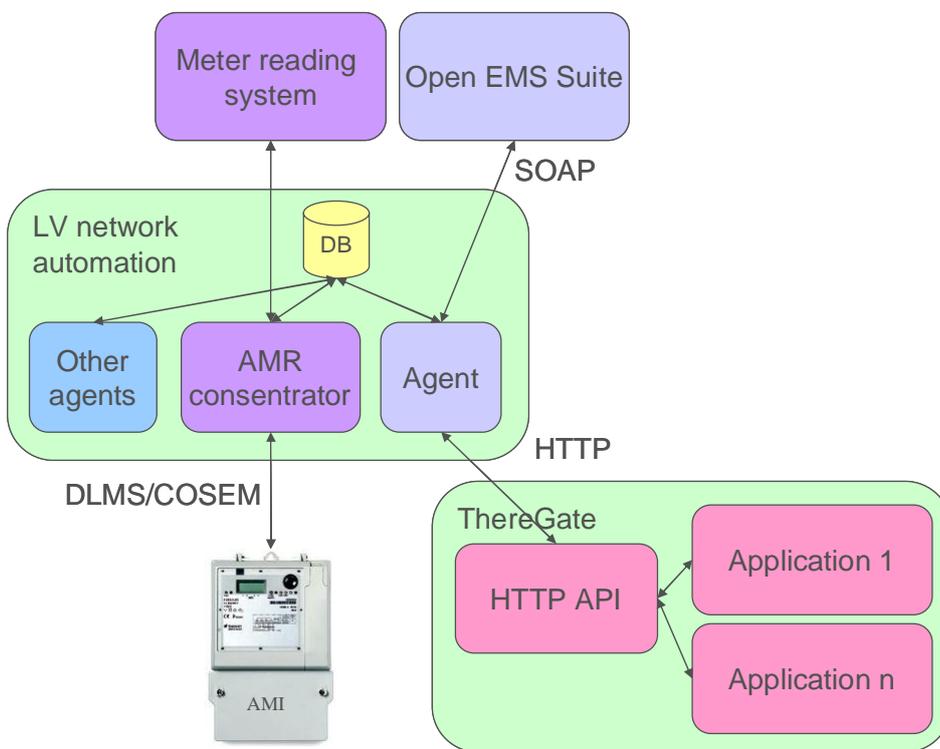
Figure 4.2. Integration of OES and ThereGate.

5   FUTURE TOPICS

The development of demonstration environment will be continued in Smart Grid and Energy Market program. Many applications have already planned to be implemented but the design of IT architecture has taken most of the time so far. Planned applications are:

- Monitoring of resources

- Network overload management

- Smart home energy management (minimization of charging costs and peak load reduction at customer connection point)

- LV network management

- Production following charging of electrical vehicle

IT system itself needs also development. Currently the architecture is very centralized around OES and control centre systems. The distributed IT architecture would be more flexible and scalable than centralized IT system. Aggregation of information may not be totally avoided but the communication need should be minimized and decision making done as close to measurement points and active resources as possible.

If an intermediate information and automation system is added between aggregator and home energy management some smart grid applications may be distributed. Figure 4.2 describes a system where LV network management is distributed instead of centralized DMS management. The architecture of Figure 4.2 enables integration of home and LV network automation functions. For example LV network loading information might be available for LV network management function at LV network automation device or even for all ThereGates at that network area. This would make LV network level decision making easier. Smart grid functions like delivery of surplus energy to neighbours becomes also possible.

Distributed system is also possible inside the home energy management. Part of decision making may be distributed to so-called intelligent devices like intelligent thermostat which may include e.g. frequency dependent load shedding application. The development of sensor networks makes it possible to directly communicate between a measurement and a regulating unit. However it is good to have some kind of overall supervision of home energy management and a single interface to upper information and automation systems.

6 REFERENCES

ABB TTT, (In Finnish)

http://www02.abb.com/global/fiabb/fiabb255.nsf/viewunid/C46D5509D325D21AC225695B002FB07B/$file/203_0007.pdf

Short, J. A., Infield, D. G. and Freris, L. L. 2007. "Stabilization of Grid Frequency through Dynamic Demand Control", IEEE Transactions on Power Systems, vol. 22, 3, pp. 1284–1293, 2007

Rautiainen, A., Repo, S., Järventausta, P. 2009a. "Using Frequency Dependent Electric Space Heating Loads to Manage Frequency Disturbances in Power Systems". PowerTech 2009, IEEE PES, Bucharest, Romania, 6 p.

Rautiainen, A., Repo, S., Järventausta, P. 2009b. "Using Frequency Dependent Charging of Plug-in Vehicles to Enhance Power System's Frequency Stability", European Conference SmartGrids and Mobility, 8 p.