DEMONSTRATION ENVIRONMENT FOR SMART GRID APPLICATIONS

Interactive Customer Interface (INCA) project

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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 automation 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 automation (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.
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# ABBREVIATIONS

<table>
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<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>AMI</td>
<td>Advantage Metering Infrastructure</td>
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<td>API</td>
<td>Application Program Interface</td>
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<tr>
<td>CIS</td>
<td>Customer Information System</td>
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<td>DB</td>
<td>Database</td>
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<td>DER</td>
<td>Distributed Energy Resources</td>
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<td>DG</td>
<td>Distributed Generation</td>
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<td>DMS</td>
<td>Distribution Management System</td>
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<td>DNO</td>
<td>Distribution Network Operator</td>
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<td>EV</td>
<td>Electric Vehicle</td>
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<tr>
<td>GUI</td>
<td>Graphic User Interface</td>
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<tr>
<td>HTTP</td>
<td>Hypertext Transfer Protocol</td>
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<td>ICT</td>
<td>Information and Communication Technology</td>
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<td>IT</td>
<td>Information Technology</td>
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<td>NIS</td>
<td>Network Information System</td>
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<td>OES</td>
<td>Open EMS Suite</td>
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<tr>
<td>OSS</td>
<td>Operation Support System</td>
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<tr>
<td>Resource</td>
<td>Electrical equipment (generator, load, etc.) which may be controlled by aggregator or by home automation</td>
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<tr>
<td>RTDB</td>
<td>Real-time database</td>
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<td>SCIL</td>
<td>Supervisory Control Implementation Language</td>
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<td>SNMP</td>
<td>Simple Network Management Protocol</td>
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<td>SOAP</td>
<td>Simple Object Access Protocol</td>
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<td>TSO</td>
<td>Transmission System Operator</td>
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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 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.
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. 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 resource requires tailoring. Home automation 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 automation 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 Smart grid use cases

Here are described two use cases where above ICT system could be utilized.
1.2.1 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 automation 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.

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 automation
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)

1.2.2 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
- Low voltage 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 low voltage network overloading could be realized e.g. at secondary substation or the reasoning of medium voltage 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.
1.3 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 automation (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 2. Home automation laboratory.
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
  - What is contracted (smart grid applications which may utilize resource)
  - With who (resource)
  - Period {for the time being, fixed}
  - Special conditions (if default parameter settings for smart grid applications are not applied)
- Contracts of smart grid applications
  - What is contracted (smart grid applications to which aggregator provides controllable resources)
  - With who (DNO, energy market participant, etc.)
  - Period {for the time being, fixed}
  - Default parameter settings for smart grid applications
- Storage of real-time measurement and status data

Collecting data
- Available resources
  - The state change of resource {on or off}
  - EV related information {starting / stopping of EV charging, estimated need for energy, charging current, wished time when battery should be fully charged, etc.}
  - 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:
Aggregator 8

- Timestamp
- Data \{current, voltage, power, temperature, etc.\},
- Type of data \{instantaneous value, mean value (+window size) or root-mean-square value (+window size)\},
- Trigger \{time interval, event, change\},
- Trigger threshold \{no threshold, 1 \%, 10 \%, etc.\}, etc.

- Other data
  - Temperature forecasts for each area

- Data from disturbance situations
  - Event: timestamp, duration, type of control actions, amount of control actions and disturbance cause
  - 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 automation and EV charging point
- Setting parameters to applications in all levels
- Reporting
  - available resources to upper level systems in real-time
  - usage, value (money, reduced CO2 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 Open EMS Suit – data integration platform

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, and configuration management; easy to be extended and customised for customer needs. Therefore we choose OES to aggregate data from ThereGate.

The typical workflow of using OES is:
1. Modelling network resources. In our case, we model ThereGate and its connected devices as Managed Object classes, so OES regards ThereGate and the devices as network elements.
2. Implementing mediation components. Mediation is a software component that provides the necessary data conversions and protocol-level integration between
network elements and OES system. In this way, OES is able to receive data from network elements, and “understand” these data.

3. Making adaptations in OES SDK. An adaptation is configuration data which defines the details of a specific element type. It configures, for example, user interface, database, mediations, and business rule for the element type.

4. Deploying adaptations. When deploying, OES create database tables according to the configuration data.

5. Creating element instances. When element instances are created, specific element instance is mapped to specific element type. In the case of integrating ThereGate, after we have defined “ThereGate” element type by making adaptations, for each ThereGate instance integrated to OES, we need to create one “ThereGate” element instance for it.

6. At this point, OES starts accepting data from element instances and keep them in database. These data are measurement data, alarms, etc. We can develop software components or use build-in applications to access these data, and present them to user in GUI (Graphic User Interface), or forward them to upper layer information systems, e.g. SCADA system.

Because OES was originally designed for managing a set of network device elements, and typically these elements use SNMP (Simple Network Management Protocol) to communicate with management system, OES provides build-in support for integrating these types of elements. In order to integrate other type of elements like ThereGate, more integration work is needed – i.e. implementing special mediation component for ThereGate.

2.2 Smart Grid applications at Open EMS Suit

The following figure illustrates the system architecture of our Aggregator solution: ThereGate is equipped in customer’s house, controlling and measuring all kinds of electric devices, like Advantage Metering Infrastructure (AMI), Distributed Energy Resources (DER), Electric Vehicle ... A piece of software called Agent is running on some computer, and it has Internet connections with both ThereGate and OES. The agent is implemented as a Web Service. It uses Hypertext Transfer Protocol (HTTP) to fetch data (e.g. measurement data, alarms,...) from ThereGate, processes and then sends them to OES via Simple Object Access Protocol (SOAP) messages. OES gathers these data into Database. From Database, OES build-in applications can read data, visualize them on user’s Web browser. The user can sit anywhere, as long as his web browser has Internet connection with OES. OES can also forward data to SCADA system.
One disadvantage of using OES in Smart Grid application is: generally OES only accepts data from network element, not the other way around. Therefore OES cannot directly send command to managed element. But with agent, we can solve this problem in a flexible way.

Imagining one fictional scenario, AMI is doing measurement at customer’s house. And suddenly AMI shows voltage is too high. The following steps show how the system works:

1. AMI is doing measurement at customer home. And AMI get a measurement data, it shows voltage is too high. ThereGate notices this event soon.
2. The agent is polling status update from ThereGate very e.g. 30s. So agent also knows that "AMI shows voltage is too high".
3. Then the agent reports this event to OES in SOAP messages.
4. This event arrives at OES system. After being processed by mediation and build-in applications in OES, user can notice an alarm from his Web browser’s GUI, it says “Alarm: AMI shows voltage is too high at somewhere”.
5. Then the user can report this alarm to responsible operator, or trigger some command to handle this event automatically.

Figure 3. IT architecture for aggregator.
3 HOME AUTOMATION

Home automation 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 automation 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 automation 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.

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. 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.

3.2.1 Frequency dependent load shedding

Frequency of the voltage of the power system works as an 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.

Figure 4 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 4. 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 power 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.

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 5 presents a principle of peak load reduction, in which some big loads are switched off and on to manage the peak power. 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 6. 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 5. Principle of peak load reduction system.
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 power of an electricity connection, and use the “free capacity” which is available every moment. 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.

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.

Third application is control application for frequency dependent load shedding. When initialized, it searches all 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.
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 OES 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 are currently under development.

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 really high and the connection between OES and ThereGate devices might have limited capacity.

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 will be 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 in the demonstration environment in the future.

4.2 Data exchange

Diversity of possible applications 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 after the data transfer interfaces between the systems are done. The messages will have a schema 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 of 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
- Activated applications
- Measurement data (common for all resources):
  - Indoor temperature [°C]
  - Outdoor temperature [°C]

Monitoring of resources (real-time data)
Resource data:
- Resource ID
- Status {on/off}
- Timestamp of status information (when information was updated) [UTC]
- Duration of current status [s]
- Measurement data (depends what is available):
  - Active power demand / production [kW]
  - Reactive power inductive / capacitive [kVar]
  - Voltage [V]
  - 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 end this means OPC DA server and in OES end this means XML files. To make
these interfaces compatible with each other separate agent software between the systems is required. Furthermore, OPC DA is based on Microsoft DCOM and therefore doesn’t support other operating systems than MS Windows. As OES operates on Linux, this causes another problem which is 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 interface. The software agent between the systems is coded in Java and it provides the necessary data transformations between XML files and OPC UA. Towards SCADA the agent operates as an OPC UA client. The components uses in data transfer between OES and SCADA are shown in Figure 7.

![Diagram](image-url)

Figure 7. Integration of OES and SCADA.

### 4.3.2 – 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 can be queried by the agent e.g. 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 low voltage network management. The architecture of the communication components is shown in Figure 8.

Figure 8. Integration of OES and ThereGate.
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)
- Low voltage 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 automation some smart grid applications may be distributed. Figure 8 describes a system where low voltage network management is distributed instead of centralized DMS management. The architecture of Figure 8 enables integration of home and low voltage network automation functions. For example low voltage network loading information might be available for low voltage network management function at low voltage network automation device or even for all ThereGates at that network area. This would make low voltage 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 automation. 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 automation and a single interface to upper information and automation systems.
6 REFERENCES

ABB TTT, (In Finnish)

