Smart Grid Gotland
Pre-study

GEAB, Vattenfall, ABB, KTH

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EXECUTIVE SUMMARY

Today's electricity networks need to be modernized in order to handle larger amounts of renewable generation. Typically the production is more distribution than previous. Further the involvement of the end user is important to be able to handle the balance between production and consumption. This is today refred to as the Smart Grid. . The Smart Grid is a prerequisite for increasing the share of sustainable electricity production from renewabels, primarily wind power, and thereby fulfilling the European Union's climate targets (20/20/20 targets). New technical solutions have to be developed and a new mindset introduced for building more flexible and sustainable energy systems and efficient energy use. Also new market models and a more sophisticated electricity production and distribution system have to be developed to support an increased number of active players, for example service providers, third party business aggregators and RES producers to develop products and services to customers.

The Smart Grid Gotland R&D project intends to develop strategies for the planning, construction and operation of a fully developed, large-scale Smart Grid, including a large share of intermittent production, primarily from wind power in the distribution network. New market models and services will be developed to involve active customer participation and pave the way for new market players. Through this development of the future smart distribution grid, consumers and producers will be fully integrated in a R&D project that is likely to become an international model for a long-term sustainable electricity power system.

The Smart Grid Gotland project intends to upgrade the existing power system on the island to a true Smart Grid system. The project will implement new and advanced equipment and methods to facilitate significantly increased hosting capability of renewable energy sources (RES) utilisation in the network system of Gotland. In order to accomplish the mentioned complicated tasks, the Smart Grid Gotland project will in principal implement and utilise the following technical improvements, innovations and enablers. The Smart Grid Gotland project constitutes of:

- Upgrading present distribution system by implementing new Smart Grid technology and provide improved system support for advancements in system control and monitoring of LV/MV systems, including so-called last-mile-SCADA, for adding significant betterment in system management and consequently facilitate raising the hosting capacity of RES even at lower voltage levels.

- Demonstrate the ability to support introduction of additional wind power generation in the distribution network by integrating battery energy storage facility in combination with a static VAr compensator (SVC) providing the possibility to control active and reactive power injected into or retrieved from the system. The Energy Storage will be one important part in a system actively balancing the local production, typically wind generation, and local loads. The so called Demand Response where active consumers respond to a situation where production is low and price increases needs systems to support this.
- Introduce and test possibilities for consumers to actively participate in demand respond activities to balance the intermittency of the RES generation by utilising the flexibility of consumer consumption and demand by providing novel technology metering, energy management facilities, load control via aggregators, utilise advanced tariffs, charging of EV/PHEVs and improve in-house RES generation.

The Smart Grid Gotland approach will be able to represent Smart Grid development for increased network hosting capacity for consumers' utilisation of renewable energy resources (RES) and the consumers' integrated Demand Participation (DP). By implementing Smart Grid technology, improved system control, energy storage, utilisation of RES, consumer Demand Participation and EV/PHEV charging may be coordinated and subsequently will facilitate for optimisation of implementation and generation of renewable in the selected networks and consequently reduce the CO_2 footprint.

The Smart Grid Gotland Project enables a possibility to test components and systems together, which has not been done before. The components and techniques are known, and some have been tested separately, but not together, integrated in a system. The pilot can provide answers to questions on:

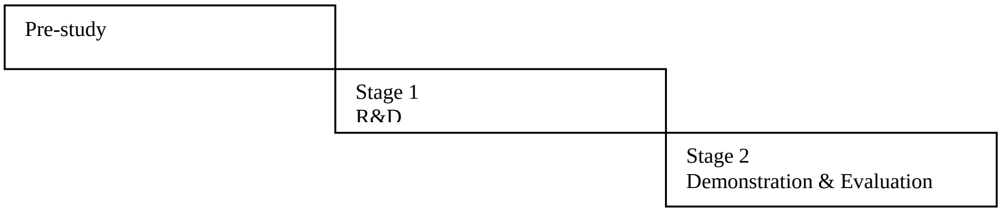
1. How the components act when provided a possibility to communicate with each other;
2. Which benefits they enable as a system, that they do not provide separately; and
3. Which challenges that arise due to unforeseen effects

The total picture gives a larger understanding of the Smart Grid as a whole and a valuable knowledge base about the functions of separate components, possibly also leading to the fine tuning of the system in order to be faster and more intelligent; to the development of new services and to the development of new roles such as aggregators.

The Pilot Smart Grid Gotland also provides a step towards a full-scale implementation of Smart Grids in Sweden. There are major challenges on the way to the large-scale Smart Grid roll out and a strong need for strong drivers to make the investments viable. The Smart Grid provides benefits to all parts of the electricity value chain, starting with the electricity generation, continuing with the electricity distribution and ending with the electricity consumer. The investments made by participants' up-streams often provide benefits to participants down-stream in the value chain. Participants in the value chain cannot always pass on increased costs to other participants that enjoy the benefit. Therefore, if the benefit is not sufficiently large for the participant taking the investment there is little or no incitement to invest.

Deliverables from the pre-study, that has been ongoing during a six-month period, starting the 23 of November 2010 and ending at the 23 of May 2011, can be summarized as:

- A complete project description has been produced; outlining the scope and parts included in the future project, as well as defining time plan and costs. This will be the base when demonstrating the future Smart Grid capabilities regarding both technologies and market innovative solutions. A financing plan, involving NER300 support, national support from Swedish authorities and participating partners are also part of the deliverables from the pre-study work. The following is a picture describing the financing plan.



- Financing of pre-study: 25% Swedish Energy Agency, 75% Industrial Partners
- Financing of stage 1, R&D; 25% Swedish Energy Agency, 75% Industrial Partners
- Financing of stage 2, Demo.; 50% NER 300, 50% Industrial Partners.
- A legal agreement between the pre-study industrial partners has been produced, defining cooperation and obligations related to Smart Grid Gotland pre-study. A letter of intent is also signed between the partners ABB, Vattenfall and GEAB, where the partner companies have agreed on a NER300 financing plan.
- The pre-study contains suggestions of tests of new innovative solutions related to new products, new services and a new Smart Grid system approach, which have not been demonstrated before. New innovative ways for end customer participation are described as well as novel technical solutions.
- Several possible academic R&D projects have been identified, where both more general Smart Grid topics as well as specific topics related to Smart Grid Gotland are defined.

SAMMANFATTNING

Dagens elnät behöver moderniseras för att bli mer intelligenta och effektiva. Det är en förutsättning för att öka andelen förnybar elproduktion från framför allt vindkraft och därigenom kunna uppfylla Europeiska Unionens klimatmål (20/20/20 målen). Nya tekniska lösningar behöver utvecklas och ett nytt tankesätt introduceras för att bygga mer flexibla och hållbara energisystem och bli effektivare i energianvändningen. Likaså behöver nya marknadsmodeller utvecklas och mer sofistikerade system för elproduktion och eldistribution som kan stödja ett ökat antal aktiva aktörer, exempelvis tjänsteleverantörer, tredjeparts aggregatorer och producenter av förnybar energi.

Smart Grid Gotland är ett forsknings- och utvecklingsprojekt som ska utveckla strategier för att planera, bygga och driva ett fullt utvecklat storskaligt smart elnät, som omfattar en stor andel intermittent produktion, framför allt från vindkraft, i distributionsnätet. Nya marknadsmodeller och tjänster kommer att utvecklas för att skapa delaktighet med konsumenterna och bana väg för nya marknadsaktörer. Genom denna utveckling av det framtida smarta distributionsnätet kommer konsumenter och producenter att bli helt integrerade i ett FoU projekt som sannolikt kommer att bli en internationell modell för ett långsiktigt hållbart elkraftsystem.

Projektet Smart Grid Gotland avser att uppgradera det befintliga energisystemet på Gotland till ett fullt utvecklat smart elsystem. Projektet kommer att integrera ny avancerad utrustning och nya metoder för att det ska bli möjligt att utnyttja en större andel förnybara energikällor i elnätet på Gotland. För att kunna lösa dessa komplicerade krav kommer Smart Grid Gotland i huvudsak att utnyttja nedanstående tekniska utvecklingar och innovationer. Projektet Smart Grid Gotland ska:

- Uppgradera det befintliga distributionssystemet genom att utnyttja ny teknik för smarta elnät som ger stöd för förbättrad systemkontroll och övervakning av låg- och mellanspänningssystem, inklusive så kallad ”last-mile-SCADA”, ett system som övervakar, styr, optimerar och hanterar kraftgenererings- och kraftöverföringsnät. Detta ger avsevärda förbättringar i systemstyrning och därigenom möjlighet att öka andelen förnybar energi även vid lägre spänningsnivåer.

- Visa att det är möjligt att integrera ytterligare vindkraftproduktion i distributionsnätet genom att integrera energilagring baserat på batterier i kombination med en så kallad statisk Var kompensator (SVC, Static Var Compensator) som ger möjlighet att öka kapaciteten i det befintliga nätet genom att kontrollera aktiv och reaktiv effekt tillförd eller utvunnen ur systemet. Energilagret är en viktig del i det system som aktivt bidrar till balans melan intermittent produktion och aktiva konsumenter.

- Introducera och testa möjligheten för konsumenter att aktivt delta i system för efterfrågestyrning i syfte att balansera den intermittenta karaktären av produktion från förnybara energikällor. Detta kan ske genom att dra nytta av flexibiliteten i konsumenternas energianvändning genom att introducera ny mätarteknik, utrustning för energistyrning, lastkontroll via aggregatorer, användning av avancerade tariffer, laddning av el- och laddhybridbilar och använda mer småskalig lokal produktion av förnybar energi.

Smart Grid Gotland kommer att utveckla elnätets möjlighet att hantera konsumenternas användning av förnybara energikällor och konsumenternas delaktighet i att reglera efterfrågan av el i nätet. Genom att dra nytta av teknik för smarta elnät förbättras kontrollmöjligheterna i systemet, möjligheten till energilagring, användning av förnybara energikällor, samtidigt som konsumenternas efterfrågan och laddning av el- och laddhybridbilar kan samordnas bättre. Det ger i sin tur möjlighet att optimera hur man producerar och fasar in förnybar energi och därigenom minska utsläppen av koldioxid.

Projektet Smart Grid Gotland gör det möjligt att testa komponenter och system tillsammans på ett sätt som inte gjorts tidigare. Komponenterna och teknikerna är kända och några har testats var för sig men inte ihop i ett system. Piloten kan ge svar på frågor som:

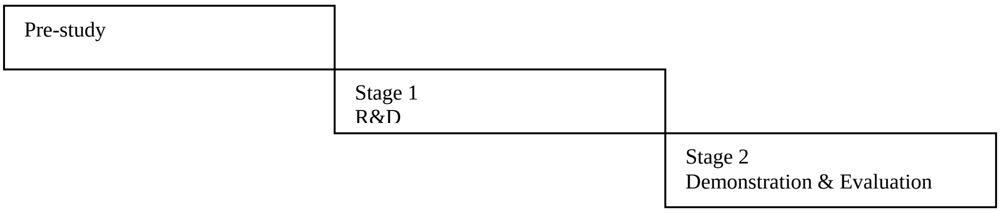
- Hur komponenterna beter sig när de ges en möjlighet att kommunicera med varandraVilka fördelar de ger som ett system som de inte ger var för sigVilka utmaningar som uppstår på grund av oförutsedda effekter

Den totala bilden ger en större förståelse för det smarta elnätet som helhet och en värdefull kunskapsbas om funktionerna av separata komponenter. Det kan också leda till att systemet kan finjusteras för att bli ännu bättre och mer intelligent samt att nya tjänster och roller såsom aggregatorer utvecklas.

Pilotprojektet Smart Grid Gotland innebär också ett steg mot en fullskalig introduktion av smarta elnät i Sverige. Det finns stora utmaningar på vägen mot att kunna introducera ett fullskaligt smart elnät och ett stort behov av starka drivkrafter för att göra investeringarna genomförbara. Smarta elnät ger fördelar för alla delar av elenergins värdekedja, från elproduktionen, via eldistribution till slutligen elkonsumenterna. Investeringar gjorda av deltagare tidigt i värdekedjan ger ofta fördelar för deltagare senare i värdekedjan. Däremot kan deltagare i värdekedjan inte alltid skicka vidare kostnader till andra deltagare som drar nytta av fördelen. Om fördelarna för dem som investerar inte är tillräckligt stora finns bara små eller inga incitament alls att investera.

Resultaten från förstudien som har pågått under en sexmånadersperiod, med start den 23 november 2010 och slut den 23 maj 2011, kan summeras som:

- En komplett projektbeskrivning har tagits fram med en beskrivning av omfattning och delar i det framtida projektet liksom att specificera tidplanen och kostnaderna. Det blir basen för att kunna visa egenskaperna för framtidens smarta elnät avseende teknik och innovativa marknadslösningar. En finansieringsplan, inklusive stöd från NER300, svenska myndigheter och deltagande partner, är också ett resultat av arbetet i förstudien. Finaniseringen, som förutsätter godkända bidragsansökningar, ser översiktligt ut som följer;



Finansieringen av förstudien; 25% Energimyndigheten/Vinnova, 75% Industriella Partners

Finansieringen av Steg 1, R&D; 25% Energimyndigheten/Vinnova, 75% Industriella Partners

Finansieringen av Steg 2, Demonstration; 50% NER300 (EIB), 50% Indutriella Partners

- En juridisk överenskommelse mellan parterna i förstudien har tagits fram, i vilken samarbetet och förpliktelserna relaterade till Smart Grid Gotland läggs fast. En avsiktsförklaring (letter of intent) har också undertecknats mellan projektets partner ABB, Vattenfall och GEAB, där de deltagande företagen har enats om finansieringsplanen i NER300.
- Förstudien innehåller förslag till tester av nya innovativa lösningar som omfattar nya produkter, nya tjänster och en ny ansats för smarta elnät som inte demonstrerats tidigare. Nya innovativa sätt att inkludera kunddeltagande i elsystemet beskrivs också liksom nya tekniska lösningar.

- Flera tänkbara akademiska forsknings- och utvecklingsprojekt har identifierats där både generella frågeställningar för smarta elnät och specifika frågor för Smart Grid Gotland definieras.

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1 INTRODUCTION

In this chapter an overview to the Smart Grid concept is given as well as a brief presentation of the pre-study project organisation and execution.

1.1 Smart Grid overview

What is a Smart Grid? The definitions of the term "Smart Grid" are many, mainly distinguished by the type of technologies and systems that are included. The distinction between a regular grid and a Smart Grid can sometimes be quite difficult. The European Technology Platform Smart Grids[1] defines Smart Grids as:

An electricity network that cost efficiently can integrate the behaviour and actions of all users connected to it – generators, consumers and those that do both – in order to ensure a sustainable power system with low losses and high levels of quality, security of supply and safety.

A Smart Grid can be seen as the convergence of IT, telecom and the electricity market. It is a platform that enables the functioning of distributed intelligence, communication technologies and automated control systems in order to response to the environmental, political and technical demands on the electricity distribution system. Smart grid facilitates the desired actions of its users and these may include the deployment of customer participation through distributed generation, demand side management and demand response as an answer to the introduction of dynamic tariffs, energy storage systems and the optimal expansion and management of grid assets.

The term Smart Grid can include both the transmission system and the distribution system. In the Pilot Smart Grid Gotland, both areas are touched upon since the 70 kV lines are, to some extent, used as transmission lines. From a system perspective Gotland regulates its frequency and short circuit power.

New products and technical solutions will be integrated at the electricity end-use side and in the distribution and management systems, which separately, but even more so jointly, will change the efficiency and possibilities of the system.

1.1.1 Driving factors

The driving factors behind the introduction of a Smart Grid can be grouped into five categories;

1) Renewable energy generation
2) Active end-user participation in the electricity system
3) EU energy independence and security of supply
4) Increased efficiency in the distribution system
5) Regulatory framework.

A Smart Grid enables the integration of more **renewable energy generation** into the grid and thereby contributing to the EU 2020 target on renewable energy. This applies both for small and large-scale wind farms and for small scale distributed generation of renewable energy such as photovoltaic installations on the roofs of private houses. A high degree of electricity generation by wind entails specific challenges to the grid such as dynamic voltage control, steep changes in generated power, power quality and grid stability. These challenges can be overcome by components

[1] http://www.ei.se/upload/Internationellt/E10-EQS-38-05_SmartGrids_Conclusions_10-Jun-2010%5b1%5d.pdf

of the Smart Grid. The possible imbalances from intermittent generation could partly be compensated from a more dynamic demand side. An increasing number of small-scale distributed electricity generation plants impose other challenges to the Smart Grid, including the ability for two-way communication and transportation of electricity in the local grid as well as the integration of distribution management systems and measurement systems. The ability to include distributed generation not only applies on the driver to increase renewable energy generation, but also applies for another driver, the "**end-user empowerment through active participation** in the electricity market. A consumer of energy can, via integration in a Smart Grid, act as a producer of electricity, creating a new actor, a so-called "prosumer". Increased renewable energy generation will also have positive impact on the **energy independence and security of supply** of the European Union, as the dependence of imported fuel such as oil and natural gas decreases with increased electricity production from local renewable sources such as wind.

A tangible effect from a Smart Grid is an overall **increased efficiency of the electricity distribution system**, which contributes to the EU 2020 target on energy efficiency. Several components deployed in the regional and local grid, automated and monitored remotely by interacting IT systems, will optimize the distribution system. The optimized distribution system reduces transfer losses in the grid since power flows will be shared in a more optimal manor, peak loads will be reduced and voltage levels will be controlled. Further, in the optimized distribution system faults will be detected, and the number of as well as the lengths of the outages will be reduced. The effects of such improvements are:

- Reduction of maintenance cost for the distribution system operator (DSO);
- Optimized use of existing grid infrastructure;
- Higher power quality and lower number and shorter duration of outages;
- Enhanced customer understanding of electricity consumption by communicating and visualizing consumption meter data.

The reduction of the number, and lengths, of outages also relates to the fifth driving force of the introduction of Smart Grids, the regulatory framework. In 2012, the Swedish electricity grid regulator, the Swedish Energy Markets Inspectorate, will introduce a renewed performance-based incentive regulation that will determine the allowed tariff that the DSO can charge the customer, as well as the penalties charged, or rewards, for distributing poor or high quality electricity. The tariffs, penalties and rewards will be based on performance indicators such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI), and will encourage cost-efficient grid investments.

1.1.2 Smart Grid components and systems

A Smart Grid is composed of components and systems that interact and communicate through IT systems for various purposes. These components and systems will be deployed in Sweden during an anticipated time frame of 10 years. The full Smart Grid will evolve with each component entering the market. Some components have interdependencies and the development can therefore be seen as an evolution where the last, more complex, steps in the mature phase are enabled by steps taken in prior stages.

The components of the Smart Grid are shortly described below:

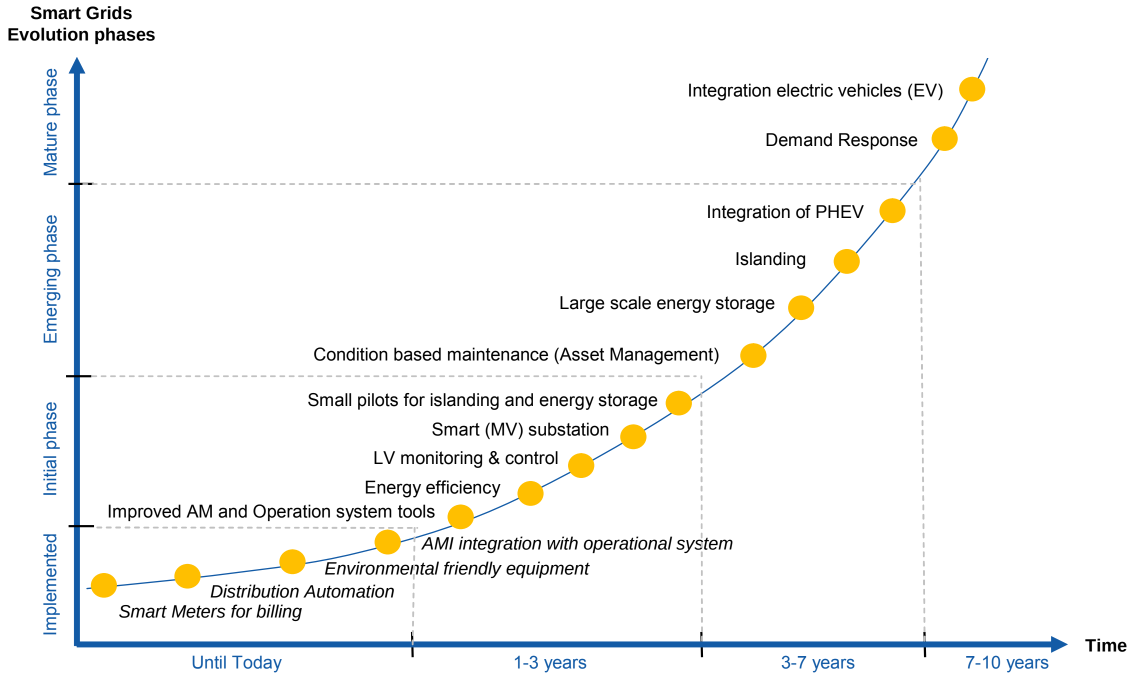

Figure 1: Smart Grid evolution.

Smart meters for billing. According to the new legislation, in force since July 1st 2009, all 5.2 million customers have received a new meter for electricity that facilitates the remote measuring of monthly values on electricity consumption.

Distribution Automation. Automation of switches and disconnectors in order to minimize the number of customers affected by outages and disturbances. To further reduce negative impact of future storms below-ground cables will be used to a larger extent.

Environmentally friendly equipment. The DSOs continuously invest in equipment with less impact on the environment, such as transformers with low losses.

AMI integration with the operational system. An Advanced Meter Infrastructure, AMI, measures, collects and analyses energy use at the customer's smart meter, se above "Smart meters for billing". It enables two-way communication with the utility company and is the prerequisite for parts of demand response, which is mentioned further down, see "Demand response".

Improved AM and Operation System tools. The supervisory control and data acquisition system, SCADA, is a computer system that monitor and control the functionality of the grid. A Distribution Management System, DMS, comprises a base SCADA system, including a measurement information system, equipped with additional planning and operations functions for the distribution system. One function of a DMS is asset management, which allows for more efficient use of the distribution grid in order to reduce losses and increase the lifetime of the equipment.

Energy efficiency. Increasing energy efficiency can be achieved by mainly three different tools – 1) to use the DMS to reduce the losses and increase energy efficiency in the distribution system, 2) to purchase equipment with high efficiency and 3) to provide information and services to the customers, in order for them to increase energy efficiency.

LV monitoring and control. The low voltage (LV) distribution grid constitutes about 50% of Vattenfall´s total grid length and has long been a blind spot for the DSO. Using the smart meters, as well as sensors that indicate the load on the LV grid, the losses can be reduced and loads distributed more intelligently. LV monitoring and control also includes the ability to connect small scale electricity production facilities at the consumer, allowing a two-way current transportation.

Smart substation. The smart substation includes the decentralization of switches and disconnectors, facilitating the measurement and automated management of the loads, quality and voltage of the electricity in the regional grid. The smart substation devices will decrease the cost of maintenance, as well as indicating outages with more precision, thereby reducing the length and number of outages. Main circuit apparatus with low losses, noise, visual impact and designed using environmentally friendly materials.

Energy storage. An energy storage facility constitutes of advanced Li-ion batteries that are integrated in the distribution system, allowing for voltage control and power quality improvements. Small-scale energy storage allows for short period of islanding, meaning that the storage can allow for an island of the grid to function without any outside input of electricity.

Condition based maintenance (Asset Management). By shifting maintenance method of the distribution grid from reactive and preventative based to predictive and condition based, many benefits can be reaped. By replacing infrastructure before incidents occurs, causing a need of shut-down, the grid will have a higher availability. Further on the maintenance strategy is more cost-efficient since equipment is not replaced earlier than needed.

Large-scale energy storage. With a large-scale energy storage facility, the storage can function not only as a voltage control facility and allow for short periods of islanding, but actually act as a power source, allowing for dynamically controlled power to be injected into, or drawn from, the grid.

Islanding. Larger energy storage facilities as mentioned above also allow for longer periods of islanding, facilitating irregular electricity production from renewable energy sources to support the “island” for a longer period of time.

Integration of PHEV. Plug-in hybrid cars, PHEVs, have in common the batteries, which provide storage capability. The storage can be charged when intermittent generation output is high, and discharged depending on market prices, wind availability, grid status or other factor, thereby providing large-scale energy storage. Further the grid infrastructure needs to be optimized if fast charging is introduced since the capacity of today’s LV network might not be sufficient.

Demand Response. Customer consumption of electricity can be managed through demand response. Consumption can be reduced during peak hours through demand response schemes, agreements between the power utility and the customer, implemented with or without intermediary actors such as aggregators.

System integration of electric vehicles (EV). A more advanced model of using the batteries in electric vehicles is the system integration, meaning that the vehicles respond to demand and supply conditions. Charging is steered to periods of low output, but system integration includes that the batteries also can deliver electricity to the grid during peak hours.

1.2 Project overview

Today's electricity networks need to be modernized in order to become smarter and more efficient. This is a prerequisite for increasing the share of sustainable electricity production from primarily wind power and thereby fulfilling the European Union's climate targets (20/20/20 targets). Therefore, we have to develop new technical solutions and introduce a new mindset for building more flexible and sustainable energy systems. We also have to develop new market models and a more sophisticated electricity production and distribution system that will create a platform for an increased number of active players, for example customers, third party business aggregators and RES producers.

The Smart Grid Gotland R&D demonstration project intends to develop strategies for the planning, construction and operation of a fully developed, large-scale Smart Grid, including a large share of intermittent production, primarily from wind power in the distribution network. New market models and services will be developed to pave the way for new market players. Through this development of the future smart distribution grid, consumers and producers will be fully integrated in a demonstration project that is likely to become an international model for a long-term sustainable electricity power system.

1.3 Project organisation

The energy companies Vattenfall and GEAB together with the supplier ABB and the Royal Institute of Technology, KTH, have during the pre-study as partners developed the project outline of Smart Grid Gotland, with the main goal to develop the intelligent distribution grid of the future.

The Smart Grid Gotland pre-study has been organised in seven work packages according to the figure below.

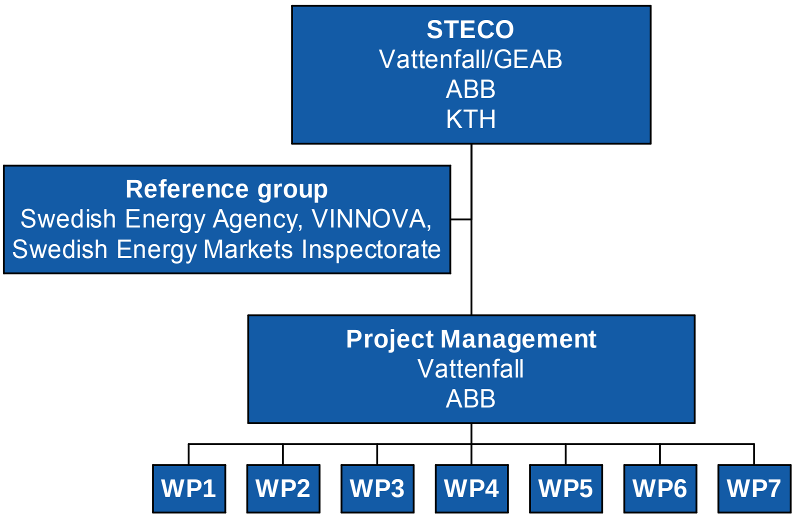

Figure 2: Pre-study organisation.

General directives and decisions have been taken by the project steering committee, where all partners have been represented. Connected to the project has also been a reference group, which have been giving valuable input to the project organisation. Project execution has been coordinated by project managers from Vattenfall and ABB. The seven work packages has been as follows:

- WP1: Smart Grid Markets
- WP2: Smart Rural Grid Development
- WP3: Distributed Intermittent Generation and Network Support
- WP4: Consumers/Prosumers and Industries Demand participation, network perspective
- WP5: Market tests and demonstrations
- WP6: Smart Grid R&D platform
- WP7: Information and Communication Technology

Reference and steering committee meetings have been held once a month to secure a good and correct progress in the project.

1.4 Project execution and economy

The pre-study has been ongoing during a six-month period, starting the 23 of November 2010 and finalised at the 23 of May 2011. Financing organisations has been the involved partners as well as the Swedish Energy Agency and Vinnova, where the later two has supported the project with 40 % of the costs. Total pre-study budget has been 10 MSEK.

2 MARKET AND REGULATORY DEVELOPMENT

This chapter describes existing and future market and business models as well as local conditions on Gotland. Smart Grid standards are also presented.

2.1 Market Model

This chapter describe an anticipated development of the Nordic Retail Market Model, based on official reports. Due to national and stakeholder differences these reports do not specific a future Nordic Market Model. However, in practice, if political goals and intentions are to be fulfilled, some alternatives are more viable than others. Based on this an anticipated future market model are described below.

In addition to technical Smart Grids features, the Gotland pilot needs to consider

- Regional regulatory aspects.
- Market harmonisation aspects, including Market Model, meter reading and settlement frequency.
- Timing aspects of this development.

These are described further in this chapter.

2.1.1 The Nordic Harmonisation process

Harmonisation of the Nordic market is an early step towards an integrated European electricity market. The goal is to integrate the Nordic retail markets and to develop a more customer oriented market with a high degree of competition between the suppliers. For this the Nordic countries regulatory regimes need to be harmonized.

Changes in regulations is implemented differently in different countries, therefore the regulatory authorities are co-operating within the joint NordREG organisation to drive this process, on assignment by the Nordic Council of Ministers.

The schedule of the Nordic harmonisation process, going from national Nordic retail markets to one common Nordic market and the Smart Grid Gotland project coincides. This is why the project need to regard the Nordic harmonisation process including regulatory changes.

The process towards a common Nordic retail market is a gradual process and could be divided into three main phases: specification, design and implementation.

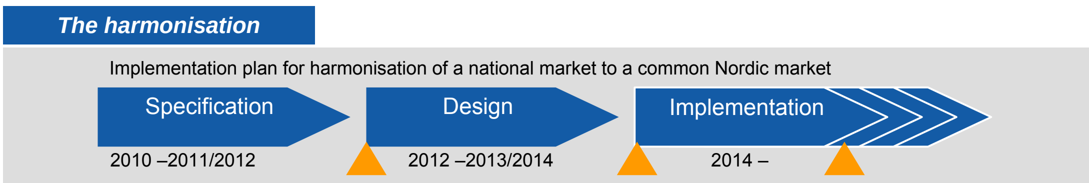

Figure 3: Process towards a common Nordic retail market.

2.1.2 Future market model

The future market model, which implies the customers are going from a dual point of contact to a single point of contact in the future, together with a number of core business processes all needs to

be taken into consideration when running the Gotland pilot.
A change of retail market model during the project need to be considered when designing live tests as present processes and support systems do not fully support a new market model.

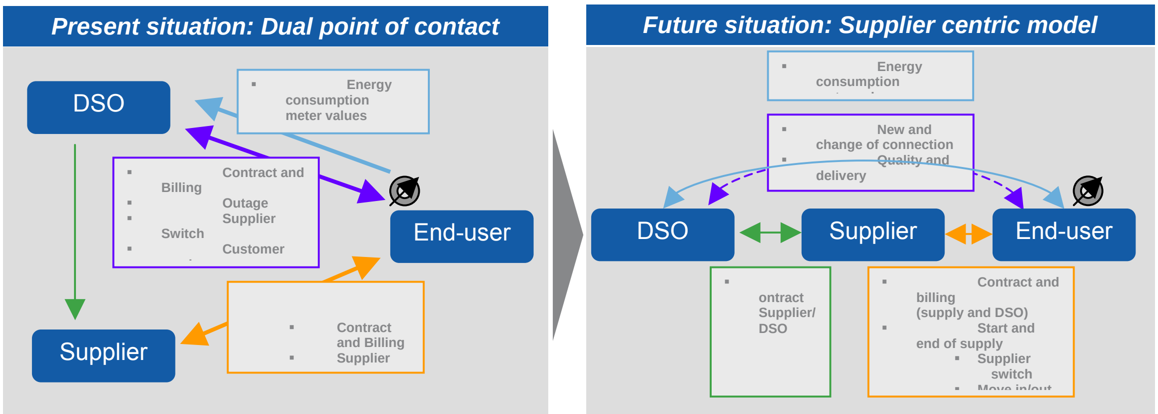

Figure 4: Present and future market model.

<u>Future market model impact on core processes</u>

When running pilots on Gotland some core business processes, influenced by the change in market model, need to be considered, as the end user benefits for these can be tested within the frames of the Smart Grid technology. The following core business processes fall into these areas:

- Billing
- Information exchange during supply
- Access to customer data and transparency

When running tests under changing conditions, future conditions need to be considered in order not to design tests based on conditions obsolete when evaluation is due, risking also results to be obsolete.

2.1.3 Hourly metering process

Hourly metering is a prerequisite to utilize the full potential of the future Smart Grids. It opens up new possibilities on the electricity market with new tariffs and contracts, but also possibilities for new roles such as aggregators and prosumers. Customers could benefit from hourly values by potential load and peak management services, but whether the benefits are worthwhile or not from an end-user perspective depend on regulation, subsidies, investments needed and contract design.

2.1.4 Future hourly metering regulation

The Swedish regulator proposes hourly metering by 2015. This might have implications on the SGG project as conditions for metering might change during the project. Since the project scope include hourly metering the legislation as such does not represent a problem for the Project. However, in practice the project should consider the required DSO process changes.

The new metering law from 2006 implicates that DSOs need to perform meter readings, and also to report these, at least monthly for <63A customers. Meters belonging to customers with a fuse larger than 63A need to be read on an hourly base. The law came into force in July 2009. The meters need to be able to be red from distance, but no regulations were presented regarding functionality of meter hardware or systems.

When the Swedish legislature passed proposition 2002/03:85,the focus was not on preparing the market for future development or on the technological requirements involved. Instead one of the reasons was to address the issues causing the public dissatisfaction with the power industry. There was no provision in the legislation for the Swedish Energy Market inspectorate (Energimarknadsinspektionen, EI) to require certain functionality. Therefore there are more than 10 different types of meter used today and not all are compatible with hourly meter readings. No regulation regarding resolution was presented within data management either, which leaves many DSOs without the opportunity of managing hourly readings without making further investments.

EI proposes as of 2010-11-25 that end users with a consumption of more than 8000 kWh annually or with fuses of more than 63A should have their consumption registered on an hourly basis, based on historical data. The proposal is based on hourly settlement. The administrative process to actually calculate the settlement is however, proposed to be conducted monthly.

The proposal recommends an implementation before 2015, in order to coincide with the Nordic harmonisation process. It suggests that exceptions from a future regulation should be made on a short tem basis (1.5 years after regulatory change) for DSOs that need to make big investments (large share of meters to be exchanged etc).

The proposal also recommends that the DSOs should have 1.5 years to prepare before the implementation.

In Finland it is regulated that 80% of all customers should be shifted to hourly metering before the end of 2013. All customers and producers with a main fuse of more than 3x63A have their consumption registered on an hourly basis since the end of 2010.

2.1.5 Distributed generation

Since the 1st of April 2010, a new legislation is to be considered on the Swedish market for micro production. Customers with a fuse below 63 A, who produce with a power less than 43,5 kW, do no longer need to pay a fee for feeding in electricity into the grid. This is valid only if the outflow of electricity is smaller than the inflow during one year, which implies that the consumers/producers will be uncertain about whether the fee is to be paid or not, until the end of the year.

The DSO needs to collect and report the electricity data on an hourly basis for the producing customers. The cost will, as in the case of consumption measurement, be held by the DSO, and thereby the other consumers. Svensk Energi has objected to this law, in terms of the hourly reading and reporting, and instead suggest reading and reporting on a monthly basis.

The new legislation has not had a major effect in the amount of new connections of micro generation. The regulation needs further development to allow e.g. net metering or net charging to make more customers interested. This is a high priority among the legislators. The regulation will probably be developed in the near future and the amount of micro generation increase.

2.2 Business Models

The above-mentioned regulatory development will naturally have impact on the market roles and responsibilities, and even new roles might emerge. In this context we focus on four market roles relevant for the Gotland project.

- Supplier
- DSO
- Aggregator
- Prosumer

The Supplier and DSO roles are naturally relevant as they have the end u ser interface and are accountable for quality of delivery. On Gotland the local DSO have responsibility for system frequency, which is why there is no need to include the TSO role in this context.

In additions to these roles we want to introduce both the Aggregator and Procumer roles. As a consequence of hourly metering, these roles will be technical possible to establish. Whether or not they are financially viable is not evaluated yet. In order to have data as basis for such an analysis, tests are vital. Meanwhile end-user benefits need to be artificially generated by subsidies from the project.

2.2.1 Supplier

2.2.1.1 Role

Electricity supplier, supply electricity to end users in competition with other electricity suppliers. The price is defined in contracts between the electricity supplier and the end user. The electricity supplier is in most cases also balance responsible (BRP).

2.2.1.2 Change in role in the future Smart Grid market

There are multiple factors affecting the role of the supplier in a future Smart Grid market. The supplier centric model will lead to an increased responsibility for the electricity suppliers, with increased administration but also potential to provide customer service for issues related to distribution the end-customer.

Smart Grids implementation, with customer participation and intermittent micro generation, opens up new possibilities for sales of related products. It will however, also influence quality on suppliers load forecast and thus have possible negative impact on suppliers balance power costs.

The common Nordic Energy market will lead to increased competition, but also extend the market to a common Nordic market.

Below, the effects on different areas of the business model have been summarised, to give an overview of how the supplier will be affected. Changes are written in blue typeface.

Supplier Role

- Electricity supplier supply electricity to end users in competition with other electricity suppliers
- The price is defined in contracts between the electricity supplier and the end user
- The electricity supplier is in most cases also balance responsible (BRP)

Supplier Business model

Black text: present conditions

Blue text: additional possible future conditions

- **Revenue and benefits:**
  - Core business: Sales of electricity to end-users.
  - Billing of Distribution services
  - Increased possibilities for related products and services
- **Costs:**
  - Main: Procurement of electricity (Nordpool)
  - Balance responsibility costs (BRP)
  - Distribution services
- **Price model:**
  - Market pricing (procurement cost, risk premium and margin)
  - Variable price/kWh or fixed over time
  - Flat administrative fee
  - Distribution services will either be included in supplier business or transferred to end-users transparently
- **Competitive situation:** National → Common Nordic market

Future development

- A Supplier Centric retail market model will lead to increased responsibility for suppliers and potential to provide additional services to end-users;
- Hourly metering will provide possibilities to offer demand side participation contracts, micro generation contracts and related services.
- The common Nordic Energy market will lead to increased competition, but also an enlarged common Nordic end user market

Figure 5: Supplier business model.

2.2.2 DSO

2.2.2.1 Role

The grid owner is responsible to measure distributed electricity and report to end-users, balance responsible and to Svenska Kraftnät (SvK), the data is used as basis for the physical power trade. The DSO operation is a natural monopoly, meaning that the end-user can not chose network company.

2.2.2.2 Change in role in the future Smart Grid market

The major change in the responsibility of the DSO is a result of the proposed supplier centric model. This model will lead to a reduced or limited end user interface for the DSO an in that sense, decreased responsibility .The DSO might however be required to provide distribution related customer support also in the future business model, as smaller suppliers might not have capability to provide this.

If net charge will be implemented for future Prosumers, DSO revenues might be reduced as small scale producers only will pay for net amount of electricity (consumed electricity minus generated).

Below, the effects on different areas of the business model have been summarised, to gain insight in how the different areas will be affected by the areas mentioned above. Changes in business model are written in blue typeface.

DSO Role

- Responsibility for distribution of electricity include operation, power quality, maintenance and new build of local grids and for grid connections to other grids.
- The DSO is also responsible for measurement of distributed electricity and report to end-users, suppliers/balance responsible and to Svenska Kraftnät for billing, settlement and as basis for physical power trade.
- The DSO operation is a natural monopoly, meaning that the end-user can not chose network company.

DSO Business model

- **Revenue and benefits:**
  - Revenue from cost based end-user fees and tariffs
- **Costs:**
  - Operation incl. power losses, outage compensation and customer service/customer interface
  - Maintenance and Asset Management,
  - Re-investments in distribution network
  - Smart Grid transformation investments
- **Price model:**
  - Regulated in terms of total profitability cap.
  - Fixed fee based on fuse size
  - Tariff based on distributed kWh.
  - Fee/Tariff based on used kW (power) on hourly basis

Black text: present conditions

Blue text: additional possible future conditions

Future development

- End user interface might be substantially reduces due to the Supplier Centric market model.
- DSO might, however, be required to provide customer support also in the future business model, as smaller supplier companies might not have capacity to provide DSO related customer service.
- If net charge will be implemented for future Prosumers, DSO revenues might be somewhat reduced.

Figure 6: DSO business model.

2.2.3 Prosumer

2.2.3.1 Role

The Prosumer is a new role on the market. A Prosumer both produce and consume electricity from micro generation, based on one contract/meter. The Prosumer role will be enabled, if and when the proposal in the net charge directive, which was submitted by the Swedish Energy Markets inspectorate (EI) in November 2010, goes into power.

Today, micro generators are required to have one meter/contract for feed in and one contract/meter for consumption, - in practice two different roles. New regulations facilitates for end users to feed in and consume electricity from micro generation, based on one contract/meter, although both generation and consumption is required to be registered.

2.2.3.2 Change in role in the future Smart Grid market

Conditions for Prosumers will be simplified and the possibilities for earnings will increase, based on EI’s proposal enabling net charging of Prosumers.

Procumer Role

- Alternately producer and/or consumer of electricity, but net consumer on an annually basis
- Today’s micro generators are required to have two meters/contracts; one for feed-in and one for consumption.
- Suggested new regulation enable end users to consume and feed-in electricity from micro generation, based on one contract/meter but still measure consumed and generated electricity respectively – meaning reduced grid fee

Business model

- **Revenue and benefits:**
  - From DSO 7öre/kWh for net production (produced-consumed)
  - Electricity certificates
  - Suppliers voluntarily take on generation (e.g. Bixia)
  - Subsidies
- **Costs:**
  - Costs for purchase of electricity
  - Double Grid fees (for both consumption and feed in)
  - Abolished requirement for specific feed-in contract enabling net charging and improved Business Case
  - Substantial reduction of end user costs through DSO net charging (consumed minus generated electricity) i.e. DSO fees, energy taxes and VAT
- **Price model:** today: N/A, Tomorrow: TBD
- **Competitive situation:** today: N/A Tomorrow: All suppliers
- **Market segment:** today N/A, tomorrow: Large private consumers or SME customers

Black text: present conditions

Blue text: additional possible future conditions

Future development

- Conditions for becoming prosumer will be simplified
- Possibilities for positive end user business case increased, based on EI’s proposal enabling net charging

Figure 7: Prosumer business model.

2.2.4 Aggregator

2.2.4.1 Role

The role of an Aggregator is as intermediary, enabling end users access power exchange markets, i.e. power balance market. The generic term Aggregator covers different forms of aggregation. E.g. aggregation of micro generation capacity or aggregation of end user load reductions for trading on power exchange markets. The role as Aggregator has a natural end-user interface as the basis of electricity to be aggregated origins from end users, either in terms of generated electricity or “negawatts”. Initially, the targeted segment will probably be B2B. The B2C market will probably be more dependent on subsidies and regulatory development to take off.

2.2.4.2 Change in role in the future Smart Grid market

The Aggregator is a possible new role on the market. In the same way suppliers have included the role as balance responsible in their business, it might be favourable for Suppliers to include also the Aggregator role in their business, since the aggregator have a natural end-user interface. The role might emerge where balance power are a scarce resource, as suppliers might be able to use load reduction as a means to reduce imbalance between load forecast and actual power load, and thus reduce balance power costs. Also the DSO might include the Aggregator role to use micro generation for power loss compensation or power quality purposes. This is however for tests and demonstrations to evaluate.

Figure 8: Aggregator business model.

Role

- To aggregate e.g. micro generation capacity or end user load reduction for trading on wholesale power exchange markets
- Intermediary enabling end user access to wholesale power exchange markets i.e. power balance market

Future Business model

Black text: present conditions

Blue text: additional possible future conditions

- **The aggregator role does currently not exist**
- **Revenue and benefits:**
  - Potential revenues from e.g. balance power market through system operator (TSO,DSO)
- **Costs:**
  - Systems investment
  - Information and control
  - Remuneration to end user
- **Price model:** End user contracts to be designed
- **Competitive situation:**
  - Dependent on what will be aggregated an purpose/type of Aggregator
  - The role can either be taken on by electricity suppliers, DSO's, be outsourced to an external party or taken on by new entrants.
- **Market segment:** Presumably B2B, and possibly B2C

Future development

- It might be favourable for Suppliers and/or DSO's to include the Aggregator role in their business
- The Aggregator role might emerge where balance power are a scarce resource
- Dependent on regulatory development and public subsidies on micro generation

2.3 Local conditions Gotland

In this chapter local conditions on Gotland are briefly described.

2.3.1 Choice of sites

As the Gotland project was initiated it was decided that two substations out of total approximately 20 substations should be selected for parts of the pilot project. The final choice of sites is Källunge and Bäcks.

The major reason for this choice is that Källunge is suitable for the energy storage tests, as an industry of required size is located there. Bäcks has a HVDC Light cable installed from windmill generation at Näsudden as well as the required closeness to city with appropriate end user structure. There is also a larger industry also in the in the Bäcks area.

Details of the Bäcks and Källunge substations is to be to be found in Appendix. A map of Gotland is presented in the figure below.

Figure 9: Map of the island Gotland.

2.3.2 Customer data

Customer data has been identified based on the needs from planned tests and pilots in the project. The customer data has been considered relevant mainly for tests with end-user interface.

The total volume of end-users at Källunge and Bäcks, sum up to less than 3.000 users. Out or these about 1850 have an annual consumption above 8.000 kWh and approximately 240 have a fuse size over 35 Amps. The number of end-users is relevant when it comes to recruit customers to take part in tests and demonstrations volume might be a problem when inviting end-users to take part in these tests.

2.4 Smart Grid Standards

In this chapter a Smart Grid standard overview is presented.

2.4.1 Core Standards Overview

There are a multitude of standards from several different standardization bodies, all more or less relevant to the development of Smart Grids. Obviously some of these standards are more relevant than others, and in an attempt to prioritise among these standards, the IEC (International Electrotechnical Commission) as well as NIST (National Institute of Standards and Technology) have identified a set of standards as core standards for Smart Grids.

These standards are described in the table below with regards to area of application and maturity, as well as direct commentary to their applicability to the Smart Grid Gotland project. Additional information on Smart Grid standards is to be found in Appendix.

Table 1: Smart Grid core standards.

Standards	Description	Core acc. to IEC	Core acc. to NIST	Relevant for SGG
IEC TR 62357	Power system control and associated communications –Reference architecture for object models, services and protocols	√		Useful as guide when setting requirements for coming implementations.
IEC 61970	Common Information Model & Energy management system application program interface (EMSAPI)	√	√	
IEC 61968	Distribution Management	√	√	Theoretically, the IEC 61968 standard has a perfect match. However, the standard should in the SGG project be used basically as a source of inspiration for the modeling.
IEC 61850	Substation Automation	√	√	Ongoing study of Smart Substations within Vattenfall.
IEC 60870-5/6	Telecontrol/ Facilitating exchanges of information between control centers.	√	√	
IEC 62351	Addressing the cyber security of the communication protocols defined by the preceding IEC standards.	√		In addition to providing technical specifications, the 62351-1 document provides a useful analysis approach to identify security risks on a Smart grid setting and how these risks can be mitigated by different types of countermeasures.

3 SMART GRID GOTLAND

In this chapter the specific situation on Gotland is presented as well as the aim and benefits with the Smart Grid Gotland project.

3.1 Aim, why Gotland?

The Smart Grid Gotland R&D project will be able to test and demonstrate the new Smart Grid system perspective allowing high penetration of renewable production. Both rural and urban networks are included, which makes the project unique. There are several reasons why the island Gotland is the perfect place for demonstrating the benefits of new Smart Grid distribution network solutions and services. Some of them are:

- Gotland can be seen as a scale model of Sweden in the year 2030 (more than 30% wind).
- Gotland is one of the few large-scale sites that have got the conditions of the future RES dominated energy system.
- More wind power is planned in the near future.
- Vattenfall/GEAB have the unique responsibility of controlling the frequency of the island.
- A new production grid is under discussion in order to handle the new wind power.
- A new DC link to Gotland is under the discussion by the Swedish TSO, SvK in addition to the existing DC links to mainland and the embedded DC link on the island.
- Fits well with other national R&D initiatives in Sweden, for example the EIT- InnoEnergy. This will strengthen Sweden's research capabilities.
- Highly visible location since Swedish politicians spends one week every summer on the island during "the Almedal week" and discuss energy amongst other subjects.

The R&D and demonstration on Gotland will allow a better understanding of:

- Future Business Cases of the Smart Grid both from a behavioural as well from a technological perspective
- Supporting the 20/20/20 targets by the integration of large amount of renewables in a distribution grid.
- Reliability and efficiency in a Smart Grid context (optimizing grid operation, security of supply and cost effectiveness).
- Customer participation on the electricity market.
- Integration of electrical vehicles.
- How to adopt the Smart Grid to other markets in Europe.

Both applied research and experimental development will be performed. Both up to date latest technology as well as new technical solutions will be demonstrated in new ways, hence showing the new features with Smart Grid system solutions. Realising the demonstration will result in:

- Demonstrate solutions that can contribute to EU 20/20/20 targets.
- Test of new technology used to integrate wind power in the rural distribution network.
- Test and evaluation of new services to make the end-customer participating on the energy market, for example through reduction of peak loads via load shaving.
- Development of new technical solutions, including ICT systems, that is scalable to the rest of Sweden and Europe.
- Test and evaluation of solutions with high delivery quality in distribution networks in a complex Smart Grid context.
- Based on experiences from the demonstration, delivery of knowledge that can be used for future regulations.
- An open R&D arena that also other suitable parts can use for further development of the Smart Grid concept.

The project Smart Grid Gotland is aiming at providing effective network characteristics and Smart Grid functionalities to the electricity distribution network on the Swedish island of Gotland, necessary to allow connection of maximum amount of renewable generation, which, in the case of the island of Gotland in the Baltic Sea, preferably relates to wind power.

The Smart Grid Gotland project intends to upgrade the existing power system on the island to a true Smart Grid system. The project will implement new and advanced equipment and methods to facilitate significantly increased hosting capability of renewable energy sources (RES) utilisation in the network system of Gotland. In order to accomplish the mentioned complicated tasks, the Smart Grid Gotland project will in principal implement and utilise the following technical improvements, innovations and enablers. The Smart Grid Gotland project constitutes of:

- Upgrading present distribution system by implementing new Smart Grid technology and provide improved system support for advancements in system control and monitoring of LV/MV systems, including so-called last-mile-SCADA, for adding significant betterment in system management and consequently facilitate raising the hosting capacity of RES even at lower voltage levels.
- Demonstrate the ability to support introduction of additional wind power generation in the distribution network by integrating battery energy storage facility in combination with a static VAr compensator (SVC) providing the possibility to control active and reactive power injected into or retrieved from the system.
- Introduce and test possibilities for consumers to actively participate in demand respond activities to balance the intermittency of the RES generation by utilising the flexibility of consumer consumption and demand by providing novel technology metering, energy management facilities, load control via aggregators, utilise advanced tariffs, charging of EV/PHEVs and improve in-house RES generation.

The Smart Grid Gotland approach will be able to represent Smart Grid development for increased network hosting capacity for consumers' utilisation of renewable energy resources (RES) and the consumers' integrated Demand Participation (DP). By implementing Smart Grid technology, improved system control, energy storage, utilisation of RES, consumer controlled DP and EV/PHEV charging may be coordinated and subsequently will facilitate for optimisation of implementation and generation of renewable in the selected networks and consequently reduce the CO_2 footprint.

The implemented Smart Grid technology will pave way for increased consumer participation in the power market and facilitate for consumers to take a more active role in adapting their increased RES generation and reduced consumption to a level suitable for their individual choice of comfort and energy costs.

Combining the capacity of the energy storage with consumers' active demand based on consumption flexibility, the system's possibility to encompass a larger number of RES units will be proven by balancing the intermittent RES generation with energy storage capability and demand response in an optimised manner. Furthermore by such combinations, autonomous operation mode, so-called islanding, will become possible.

Subsequently the Smart Grid development will achieve increased reliability of power supply and improved network operation efficiency, necessary for paving way for reduced costs for network losses, repair and maintenance as well as improved monitoring and controllability of the LV and MV network. Monitoring and controllability at lower voltage networks will be significantly improved by implementation of so-called "last-mile-SCADA" functionality.

The backbone for the Smart Grid development is extensive utilisation of advanced information and communication technology. The existing information and communication in the system on Gotland will be upgraded to or replaced with state-of-the-art information and communication technology (ICT), providing significantly increased communication capacity for data exchange within the system including communication facilities for enhanced control and monitoring of the network, substations, generating units and devices located at the consumer premises.

Scaling up the results of the Smart Grid Gotland project to a regional or national level will provide comparable identification of the benefits of Smart Grid technology applications that may be utilised as model for future large scale implementation of the selected technologies on a wider level and make way for future common implementation of solutions for reduced CO_2 footprint and improved consumer participation and possibilities for individual consumer choices.

3.2 Situation on Gotland

The Smart Grid Gotland project intends to upgrade the existing power system on the island to a Smart Grid. The northern region of the island is characterized by a weak power grid and a combination of wind power generation, household loads and some major industries. Balancing power is provided from the central part of the island where balancing power is accessed via the HVDC connection to the Swedish mainland. During emergency situation where the mainland connection is out of service, emergency generators in the northern region are utilized for feeding most of the island. An ongoing program of installing wind power production in the northern region will require grid reinforcements. The Smart Grid Gotland project intends to study, evaluate and upgrade this part of the grid in order to allow for the wind to be connected and operated in a safe way. This might call for additional dynamic control of reactive power as one example.

The city of Visby, the largest city on the island, is located in the central region of the Gotland grid on the west coast. South of Visby the island is connected to the mainland via HVDC links. Special control algorithms in the HVDC control system allows the island of Gotland either to import power from the mainland or export power when the wind power generation exceeds consumption. Several innovative Smart Grid solutions will be implemented and tested in the central region. A novel energy storage, which also works as a dynamical reactive power compensator, will be installed as part of the Smart Grid Gotland project and the energy storage will support several Smart Grid functions such as the operation of a smaller part of the grid in island operation with wind power generation alone. Other control functions that might be implemented are frequency control, black-start, voltage control and grid stability improvement.

In the central region of the island the Smart Grid Gotland project intents to upgrade two 70 kV substations with new protection and control for increased availability and communication as part of the Smart Grid concept. The distribution grid will partly be rebuild to the latest Smart Grid level for increased controllability allowing better supervision, higher reliability and improved communication to end consumers. In direct vicinity to the city of Visby, and directed south, is an HVDC cable link installed. The link connects the southern parts in parallel to the 70 kV AC overhead lines. The HVDC station outside Visby is based on Voltage source Converter (VSC) technology and might be operated as a dynamic reactive power compensator for the central region, providing increased system stability. The system control for the whole of Gotland is installed in Visby and the project involves additional Smart Grid functions to be added to the system control. The project plans to include a Smart Grid demo centre on Gotland where visualization on the Smart Grid Gotland project progress and functions are demonstrated. It is also expected that electric vehicles (PHEV/EV) will be introduced early in the city of Visby and the project includes charging infrastructure and Smart Grid functionality such as consumer involvement, e.g. demand response.

The largest amount of wind power generation presently is situated in the south of the island. The bulk of the wind power generation is transmitted to Visby via a 70 kV AC line and in parallel an HDVC cable link that can support increased transmission capacity when necessary. The southern HVDC station can be operated as a dynamical reactive power compensator to increase system stability. This function supports the Smart Grid and increase system stability when large amounts of renewable production are present. The network in the south of the island is modern and the Smart Grid Gotland project mainly will introduce increased measurement and control in the region in order to support the renewable energy generation. The south HVDC station voltage control will be connected to the system controller in Visby and a control for optimum voltage control is implemented as part of the Smart Grid initiative, further increasing network stability. However, basic investments have to be done, to upgrade the existing 30 kV OH-lines to 70 kV. Also some reinforcements in substations, such as HV apparatus, are needed in order to be able to transport and handle the increased electricity production.

When the source of power generation in a network area is mainly based on wind power the system stability will be decreased and other means of increasing stability than the generation units that is normally sufficient, may be necessary. Furthermore, when the generation is intermittent, as is the case with wind power generation, it is important to manage situations when generation is high and the load is low and when load is high but generation is insufficient. Balancing power will be available from other areas of the grid at certain times but it is also important to involve the consumers that on the basis of information changes the consumption and thereby actively participates in the most efficient usage of the renewable generation. As one example, consumer participation will be based on more dynamical price signals and development and testing active consumer participation, both the technical solutions needed and the market models needed, will become important parts of the Smart Grid Gotland project.

3.3 Benefits and innovation

In order to fully understand the aggregated positive impact from a smarter grid, the benefits for all parts of the energy systems need to be considered. This chapter describes some of the specific benefits from the project in Gotland. Also general benefits from a full-scale Smart Grid project on a macro level are presented.

The Smart Grid Gotland Project enables a possibility to test components and systems together, which has never been done before. The components and techniques are known, and some have been tested separately, but never together, integrated in a system. The pilot can provide answers to questions on:

4. How the components act when provided a possibility to communicate with each other;
5. Which benefits they enable as a system, that they do not provide separately; and
6. Which challenges that arise due to unforeseen effects

The total picture gives a larger understanding of the Smart Grid as a whole and a valuable knowledge base about the functions of separate components, possibly also leading to the fine tuning of the system in order to be faster and more intelligent; to the development of new services and to the development of new roles such as aggregators.

The Pilot Smart Grid Gotland also provides a step towards a full-scale implementation of Smart Grids in Sweden. Below is an outline of the main benefits that can be identified, divided into benefits for electricity generation, transmission and distribution grid, end consumer and society.

There are major challenges on the way to the large-scale Smart Grid roll out and a strong need for strong drivers to make the investments viable. The Smart Grid provides benefits to all parts of the electricity value chain, starting with the electricity generation, continuing with the electricity distribution and ending with the electricity consumer. The investments made by participants' up-streams often provide benefits to participants down-stream in the value chain. Participants in the value chain cannot always pass on increased costs to other participants that enjoy the benefit. Therefore, if the benefit is not sufficiently large for the participant taking the investment there is little or no incitement to invest. The questions arise; who has the most benefits out of Smart Grids? And how are the benefits to be distributed so that every participant gains from the Smart Grid evolution? Below are the main benefits for the different market participants described.

3.3.1 Benefits for society

In 2030 the Smart Grid will be the technical platform where the society as it whole will be able to reduce the environmental impact of the electricity system, increase the efficiency of the system, empower customers, enhance safety and improve productivity. Divided in those headings, the benefits are listed below:

Environmental impact, global warming and energy efficiency

- The society will have increased potential to integrate intermittent generation of renewable energy sources, RES, such as wind and solar power, both on large scale as well as distributed micro generation, and thereby reducing environmental impacts and emissions of greenhouse gases;
- Pave the way for E-mobility, which in its turn reduces emissions of greenhouse gases and increases the efficiency of the transport sector;
- Accelerate energy efficiency by communication and visualizing end consumption data to end consumer and thereby increasing awareness of energy consumption and environmental footprint;
- Improve the efficiency and thereby decrease distribution losses in the regional and local transmission grids, assisting in the achievement of the EU 20% target on energy efficiency;

- Installed equipment will indicate the condition of the grid, and of the equipment itself, thus indicating the need for maintenance via remote control. Hence, equipment will be replaced with longer intervals, which will reduce the use of resources and the environmental impact.

Empower customers

- The customer will be able to not only consume electricity, but also produce and deliver electricity to the grid, thus achieving a more empowered position towards the electricity utilities;
- The customers can more actively choose to lower their electricity bill by participating in Demand Response activities and to a larger extent influence the electricity markets;

Enhance safety

- Smart substations offer more protection by video and movement detectors, and will reduce injuries

Improve productivity

- Reliable delivery of electricity in the right time to the right quality improves the productivity of especially large-scale industry customers;
- The IT-based Smart Grid offers possibilities for new business within the IT and telecom industry, opening up for growth in productivity on a macro level (GDP).

3.3.2 Benefits for electricity generation utility

A Smart Grid enables the power utility to connect more wind power onto the grid. An energy utility that invests in wind power plants is dependent on a well functioning and well-designed electricity grid, optimizing the load, in order to actually deliver the electricity generated. As wind power production fluctuates greatly, large and costly grids need to be able to distribute all the electricity produced at peaks.

The fluctuations of wind power also require additional power reserves of conventional types such as hydropower, gas or other fossil power. Repeated ignitions, production increases or decreases and continuous shutdowns impose high maintenance costs and more involuntary shut-downs. If the Smart Grid can allow customers to act as reserve capacity by reducing load and can integrate storage facilities to unburden the generation plants as power reserves. The Smart Grid can also smoothen voltage drops and thus ease the burden on compensating power plants; this reduces costs for the energy utility.

3.3.3 Benefits for the distribution system operator, DSO

Smart substations reduce the need and cost of maintenance in the regional and local distribution grid, due to the fact that the components of the grid better indicate the need for maintenance on the grid and on the components. Traditional pre-set maintenance plans are thus replaced by condition-based maintenance.

The Smart Grid also disburses loads, supervises and operates the regional grid and feeders more efficiently, which lowers the losses of the grid and increases the overall energy efficiency. Another advantage for the DSO is the improvement of quality of the electricity, such as harmonic frequencies and reactive power, as the number and lengths of outages. With higher quality and less outages, the DSO is allowed by the regulator to use a higher tariff for the electricity distributed.

3.3.4 Benefits for end consumers

Large consumers of electricity such as industries sometimes have sensitive process equipment that needs reliable electricity with high quality and small voltage differences. Smart grid components can improve the quality of electricity by detecting faults, re-direct, heal and compensate for reactive power and harmonics.

The customers will benefit from less outages, both in number but also in length. Less outages are expected since faults can be detected more efficiently, and since the installed devices will indicate if the quality of the grid is deteriorating.

Large as well as small consumers can also act, not only as consumers but also as producers of electricity, with a two-way grid connection, providing the consumer the possibility to be more independent towards the electricity utility.

Large as well as small consumers can agree to actively or passively participate in Demand Response agreements with an energy utility, with or without the assistance of aggregators. The Demand Response agreements can involve the shutdown of selected equipment during certain periods of high demand, and in return a financial incentive. Further on by having a flexible consumption, the spot prices will decrease from a macro perspective since more expensive power generation is not needed during peak hours.

4 TESTS AND DEMONSTRATIONS

In this chapter Smart Grid Gotland tests and demonstrations are presented and described.

4.1 Rural grid

The tests and demonstrations within rural grid development will be to evaluate the Smart Grid equipment and applications added to the present network and to evaluate the most proper set-up and configuration. The test and demonstration will take place in a limited geographical area of the network at the island of Gotland, Sweden. The work includes to evaluate new equipment for two substations, Bäcks and Källunge, and for the rearrangement and control of the distribution network, and also to recommend suitable equipment.

The two substations Bäcks and Källunge are located at each side of the rural grid area proposed for the pilot installation. The 10 kV rural grid is in normal operation divided in two parts, one supplied from Bäcks and the other from Källunge. In special situations it will be possible to feed most of the grid from one of the substations. This area would suit very well for the Zone concept. Connected to the eastern substation is some amount of wind power generation located that could in extreme cases feed the area by its own.

The main part of the work connected to rural grid development is to design, deliver and evaluate new equipment for the two substations and for the rearrangement and control of the distribution network. Further, to enable full support of the required information exchange in the Smart Grid system is also vital.

The actual 10 kV grid suits well for the important test scenario that may be called “island mode”. The island mode test will be running by isolating a suitable part of the grid and disconnect it from the feeding 70 kV net. In this mode the area will be fully relying on the wind power supply. For to ably to keep the net stable in the island mode the voltage control and energy storage system as described in next chapter will be used.

In the technical development chapter below, the various equipment to be implemented and utilised is described. In the test phase demonstrations are to be conducted in order to validate the Smart Grid functionalities and capability in regard to improved operation, control and monitoring of substations, feeders and LV network. Basically this will incorporate validation of implemented equipment and their functions related to control systems and devises as well as interaction with systems such as AMM, SCADA, NIS, component condition monitoring and others.

In fact, each and every system, equipment, device and component suggested for this project is of course already tested for proper operation on its own at various test sites or networks. However the baseline for Smart Grid development is to combine a variety of advanced units into a complete entity for optimal operation and improved functionality that have not before been demonstrated and therefore require additional development, adaptation and validation. Consequently the demonstrations of the Smart Grid Gotland project will comprise of various tests to investigate and validate the interoperability and interfaces between the various parts including data interchange in order to reassure that the functionality and the anticipated attained benefits and improvements of the Smart Grid concept are achieved and proven reliable and hence suitable and advisable for additional implementations and utilisation in other networks.

The new technologies and facilities demand new systems support, set up and integration with other business areas of the network company. A main part of the work in the demonstration is to find efficient and cost-efficient solutions both from technological and administrative perspectives. Not least is it important that new installed equipment and technology is coordinated with systems at dispatch centres for operation management to receive a transparent supervisory operation environment for the entire network system. In this respect appropriate data communication solutions and coordination is essential and will consequently be an important part of the demonstrations. These new facilities demands new systems support, set up and integrations. A main part of the workload is to find an efficient and cost-efficient solution in this area.

Selected communication solutions as well as choice of system integration at back office will be of greatest significance to a successful outcome of the demonstration, why special attention will be paid to associated decisions accordingly.

Additionally, it is important that the demonstration will be carried out in an appropriate way so implementation costs for new technology and estimated benefits from these implementations together form credible business cases for network companies working in fully liberalized energy markets where massive implementation of DP, DER and EV/PHEV will be made possible due to the needs and requests of the consumers. Hence the important business for a network company is to facilitate and to make possible for the consumer to consume or generate energy in a way of his or hers own choice depending on climate, appliances, sensibility to interruptions, etc. Consequently the demonstration has to be conducted in a business-like way and all parts of the demonstration have to be recorded properly both in terms of technical and financial aspects as well as evaluated accordingly.

The technical pre-conditions for the anticipated demonstrations are described in the Implementation chapter above as well as in the appendix documents that form the base for this abridged pre-study main report. However below is a brief and summarised presentation of the units and systems and their interoperability to be demonstrated in the Rural Grid development part of the Smart Grid Gotland project.

4.1.1 Pilot area

The 10 kV grid includes a number of both overhead lines and cable feeders. The grid is divided in many sub-networks and a big number of remote controlled disconnectors are used in the grid.

Some data about the 10 kV grid:

- Basic power supply to the 10 kV grid is two 70/10 kV transformers (25 MVA + 6 MVA)
- The grid includes four wind power generators with the maximum power of 1970 kW (calculated energy: 2825 MWh/year)
- The grid includes five or more interfaces to other 10 kV networks
- The total grid has approximately 2800 connected customers, with a need of approx 72500 MWh per year. About 30 larger customers are involved (using >100 MWh/year).

4.1.2 Smart 70/10 kV substation

Validation of the indoor solution with new equipment and systems such as

- Disconnecting circuit breakers (DCB) without separate disconnectors and double bus bar
- MV switchgear with withdraw able circuit breakers
- Dry transformer including transformer electronic control & monitoring (TEC)
- Auxiliary power supply with LI-ion batteries
- SA system with IEDs, station level control and station LAN for
  - Supervision, monitoring and control of HV devices
  - Alarm and events
  - Measured values for presentation or use in asset management
  - Interlocking and intertrip
  - Occasional communication with the IEDs for remote setting or upload of information (e.g. disturbance files)
  - Power flow control in cooperation with the Zone concept
  - Area surveillance and intruder control system

4.1.3 Smart 10 kV feeders

Validate the Zone concept for instance in terms of

- Overview and control of the whole distribution network from the control centre using improved DMS functionality
- Implement fast, fully automatic fault localization, fault isolation, network reconfiguration and power restoration functionality, i.e. to create a self-healing power distribution network by taking into account existing loads at various locations and supply capability of alternative network configurations
- Investigate if certain functions should be included in the substation automation system or if the complete functionality should be included in the central SCADA system
- Maintenance aspect has to be taken into consideration when introducing new distributed devices in the 10 kV network and utilisation of device monitoring and information to AMS shall be evaluated
- An important part of the Zone concept is the communication, why it will be evaluated if the existing wireless network will be usable for the Zone concept or if the communication has to be improved.

4.1.4 Smart LV network

In order to be able to provide the sufficient data for the services and improvements outlined for the demonstrations of the project, the existing metering data acquisition system will most likely have to be replaced by a more modern system. Likewise the approx. 2800 meters located in the LV network associated to Källunge and Bäcks substations, have to be replaced in order to facilitate for implementation of the new monitoring and control services for the LV network. Additionally, it is anticipated approx. 2000 meters may have to be replaced at the premises of those customers participating in the customer focussed test market pilots elsewhere on Gotland. Tests for adaptation of new metering data acquisition system and data collection interfaces for selected meters will be conducted. Should new meters be mixed with older meters in the same network section, additional tests will be required. The project refers to the LV network.

Increasing the LV network controllability and monitoring includes the improved utilisation of AMR meters when not only in terms of metering consumers energy consumption but also providing information on voltage, frequency, load, flicker, etc. This The additional data available can then be managed to improve the monitoring of the power quality and to perform real-time power flow calculations needed to improve the network control and operations as well as the management of micro-scale generation and demand participation (including PHEV/EV) connected to the LV networks.

By combining this the improved AMR AMM technology with new developed equipment (prototypes) in the network and substation, new possibilities for monitoring and control of the LV network will be demonstrated evaluated and demonstrated evaluated.

4.1.5 Smart Grid systems

By implementing and integrating a new SCADA system to the existing systems at GEAB, new possibilities for monitoring and control of the network will be possible. Beside the operative system it is planned to install a copy of the system applicable for testing of new Smart Grid functionality. Tools related to both these system will be involved in the planning and design of the extensions as well as additional functionality in the power grid.

Some of the transmitted data is of technical nature while other data is customer-oriented. Each of this data has its home/ownership in the common model and is utilised by the different systems. To achieve good quality this needs to be defined and integration has to be setup in the right way. Consequently the interoperability and interchange of data has to be demonstrated.

The systems indicated below will be involved in network monitoring, control, planning and design and are presented in the chapter on implementation above.

- Meter data management system (MDMS)
- Metering data acquisition system
- Network information system (NIS)
- Distribution management system (DMS)
- Operation management system (OMS/SCADA)
- Asset Management system (AMS)
- Modelling, the multi aspect grid model

4.2 Distributed intermittent generation and network support

There are a number of different ways to utilise the benefits of a STATCOM with battery storage the main principles are described below. A more detailed presentation is provided in appendix.

4.2.1 Applications

The energy storage project will test the following applications:

Generic

- **Ramping support for wind generation:** The high increase or decrease in wind generation with respect to time requires online spinning reserve in order to mitigate any fast changes. The access to energy storage which can discharge energy can replace the online spinning reserve and hence save fuel cost.
  A special challenge associated with wind power cut out wind speed is the following. If the wind blows above a certain maximum speed, then the wind turbine is shut down due to safety reasons. A large area can be affected by such a wind gust causing a very fast disconnection of the production. The energy storage can be programmed to keep a high energy amount when wind speeds are expected to be near the cut out wind speed and discharge power if it happens and hence supports grid stability. The effect on power exchange with the 70KV will be evaluated and different strategies for the utilisation of battery capacity will be investigated (see appendix for further info).
- **Demand response with green electricity**: Having electricity price indicators in the residential, the residents keep a check on the electricity price and can take actions accordingly. Since the consumption and the production in the network system should be equal at any instant of time, the electricity pricing should be dynamic. In addition, in order to make the renewable, e.g. wind production, integrated in the community, the taxing system should favour this green electrical power. When/if the demand response function is tested

and introduced eg via an aggregator the battery storage can be used to speed up the response time of the required change in demand. this is made by ordering the battery to act immediately and operate until the response of customers is fully operational. This will be tested if the demand response is introduced in the Källunge area.

- **Improved power quality**: SVC Light improves the capability to mitigate voltage sags (e.g. reclosing events). As this is a basic function of the STATCOM the function will be evaluated in all applications.
- **Frequency support:** load-generation imbalance is mitigated by requiring “prompt” spinning reserve to discharge real power for durations up to 30 minutes under contingency operations. The DynaPeaQ system will instantaneously absorb and deliver power as the frequency fluctuates outside the normal range.
  In addition, all energy storage attached devices operating on the grid should have an emergency frequency support or “spinning reserve” functionality inbuilt. This should belong to the overriding functions which protect the device as well as the system integrity. The motivation for this is that without any grid there will be no use of the device. It is therefore proposed to evaluate this functionality in a field installation. The frequency support function will be used in the Islanding function described below (see appendix for details on the function).

Location-specific

- **Local grid support (dynamic grid voltage stability)**: SVC Light injects reactive power in a dynamic and continuous way providing grid voltage stability. Although the introduction of active power is theoretically unnecessary to establish voltage stability, analyses indicate that a small amount of active power significantly improves system performance by increasing the rate at which stability is restored and/or by decreasing the rating required of the power conditioning system, as well as the amount of reactive power needed. The difference between using only reactive and the combination of active and reactive power will be evaluated in the application.
- **Island operation**: in the event of failure of the main grid the DynaPeaQ system will perform an islanding function, where the energy storage will balance out wind production and load consumption. The location on Gotland has been chosen such that a part of the grid can be isolated for a while. This is an important feature of a Smart Grid where in case the grid is operated in island mode.

Functionalities

- **Flexibility and versatility to support different applications simultaneously**: The battery can provide low-level discharges for long periods, while also having the capability of operating at high power for short periods.
- **Energy storage is available within milliseconds from request.**
- **Single energy storage system with the ability to demonstrate the characteristics of multiple value streams.**
- **The Li-ion technology has a round-trip efficiency (dc-dc) of up to 98 %. Including the converter losses, the ac-ac efficiency is still above 90 %.**

The minimum battery voltage of 8 kV (as can be deduced from the battery voltage figures B1, B2 and B3 in Appendix B) provides optimum efficiency for conversion to 10 kVac.

Combining applications

A fundamental benefit of the flexibility of the DynaPeaQ Li-ion batteries is their ability to support multiple applications. Depending on the wind generation on a specific day, the ramping support for wind generation can be performed while maintaining the battery State of charge (SOC) above a certain value. The remaining battery energy can then support the power loads for island operation and/or frequency regulation.

To test the applications first each control will be tested separately for a specified time. The tests will be performed in a way that general conclusions can be made e.g. for scalability, performance and capacity factors. After each functionality is tested, separately testing of combinations will be performed. And the different strategies for how to utilise the total capacity of the storage will be investigated.

The result will be a set of cases that can be used for the dimensioning, evaluation and planning of future installations.

The islanding functionality will be tested first in a simulated case where the wind power output combined with the output of the energy storage totally balances the load in a specified number of feeders (without anything disconnected). Having done this a full-scale test may be made with the consent of the involved customer e.g. the vegetable industry. The development of control strategies and algorithms for this dynamic islanding scheme will be the most challenging feature of this part of the project. Of course the functionality will be introduced and if a real case occur the action and functionality will be evaluated.

4.3 Demand participation (DP)

It is important to test the future potential for the demand participation and energy efficiency from different customer segments. Likewise it is important to identify the benefits from DP for other actors like DSO, supplier and balance responsible. Also benefits for an aggregator role are of interest.

Overview of market tests for Demand Participation

The purpose of the market tests is to get more information about the DP potential based on how real customers react and how that can affect the electrical power systems.

The primary results expected from the market tests are:

- **Customer potential for load shaving** through reduced consumption by changed behaviour and energy efficiency measures. For private customers it can be e.g. better insulation and change of appliances and for industrial customers e.g. changes in industrial processes and equipment.
- **Customer potential for load shifting** by reducing consumption dynamically during a certain (shorter) period, but then consume that energy at another period. For private customer it can be e.g. heating warm water at a later time when the price is lower.

Other expected results based on changes of customer behaviour from DP are:

- **DSO potential for lower peak load in the grid** where there are customers participating in DP. An overall reduction in consumption will in most cases also reduce the peak load. However price signals may not result in a reduction of the local grid when prices are linked to a system or price-area peak.
- **Supplier/balance responsible potential for reduced risk and cost by using contribution from DP** on different markets as day ahead and intra day.
- **Aggregators** can be of different types, e.g. aggregate micro generation, aggregation of reduced consumption (“negawatts”) or reduce peak load in the grid.

An overview of the market test is shown in the figure below.

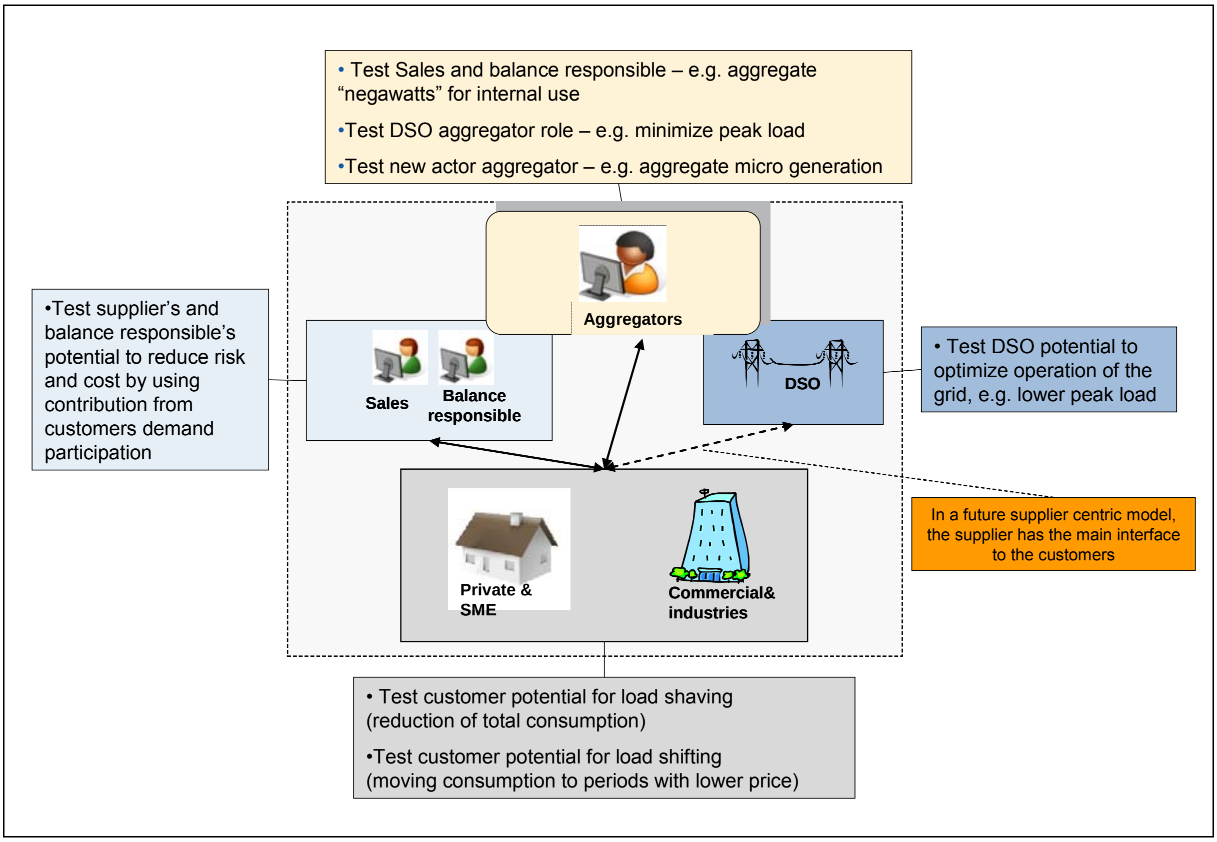

Figure 10: Overview of market test.

Customers segments for market tests of Demand Participation

An overview of customers segments included in the market test is shown in the picture below. The first segment described is Private & SME with several sub segments. Tests for the main part of the customers will be based on hourly spot prices (Sales) and and flexible time tariffs (DSO). There is also a proposal for testing reinforced price signals, which need to be further investigated. The reinforced price signals are harder coupled to the local wind production. Tests of reinforced price signals will be done on a limited number of customers. Also new grid tariffs like peak power tariffs (Sw: "effekt tariffer") will be tested for a limited number of customers. The second segment is Commercial & Industry with a number of sub segments. Tests for the main part of C&I customers will be based on hourly spot prices and grid tariffs. The proposal to test reinforced price signals is valid also for C&I customers, especially for industries with a low percentage of controllable consumption. The third segment is around the aggregator role. There is a short discussion around test of the aggregator roles, but these roles and tests need to be further evaluated before any actual tests can be defined.

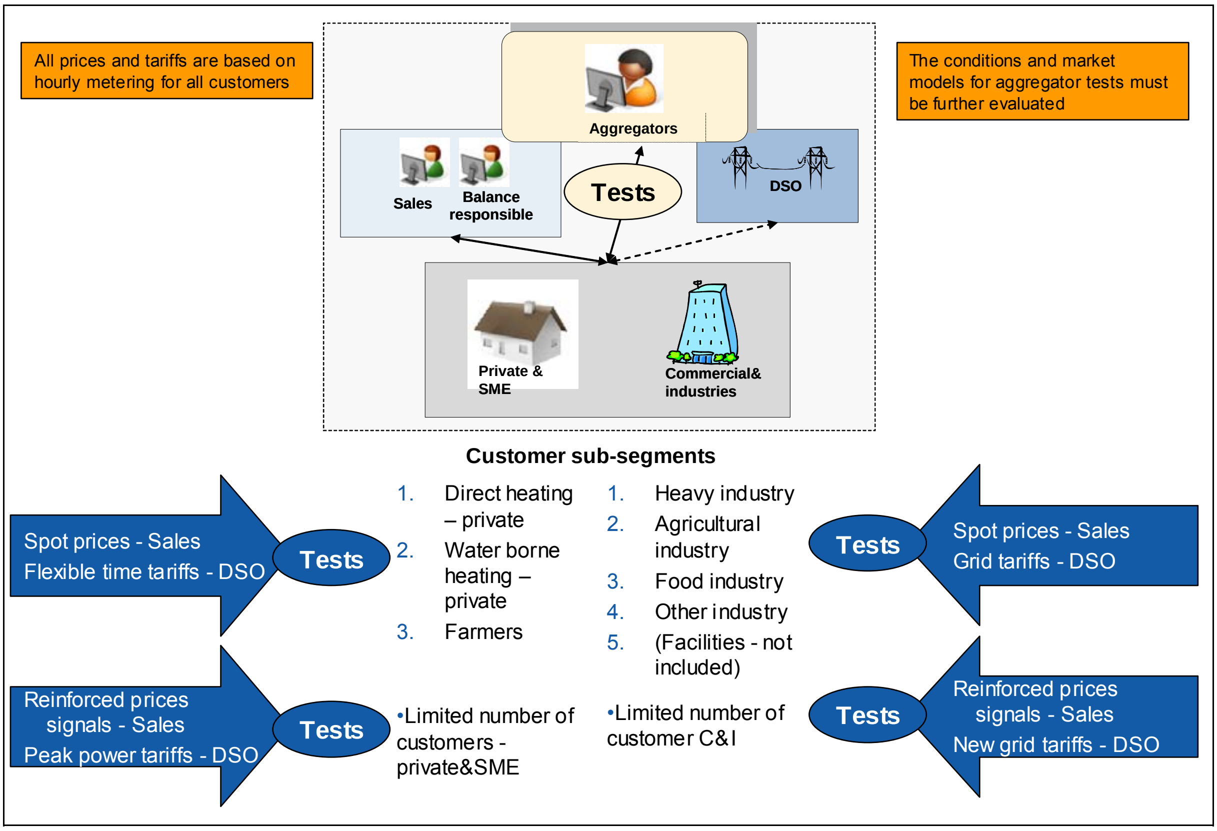

Figure 11: Overview of customer segments.

Methodology for the market tests

The methodology for setting-up the market tests are shown in the figure below. The design and planning need a long preparation period with iterations of redesign and it is important to start this process as soon as possible. The aim is to have a process where you start to use as much as possible of already available information and then work in several steps with focus groups and pre-pilots before starting the full pilot. The goal is to keep a high quality level in the tests and minimize problems for all involved. The focus is of course that the end result shall be possible to implement on the market.

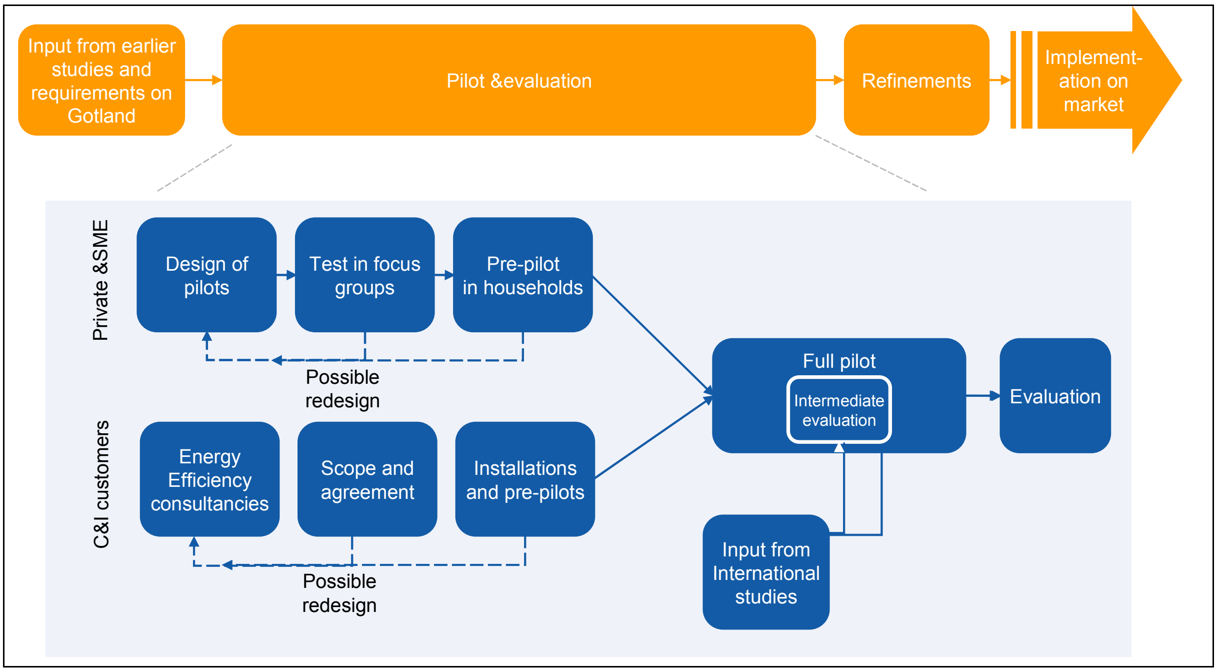

Figure 12: Overview of methodology for setting up market tests.

Experience from other tests/studies

Five different test /studies with focus on private customers (see appendix for details) in Sweden has been "food for thoughts" when designing the market pilots in general and especially for private customers:

- **Peak shaving project** is a Vattenfall project that is calculating the potential for peak shifting and shaving for private customers. The basis for the calculations is historical consumption data from real customers during a full year (hourly values). Preliminary results show that the customer's potential for load shaving and shifting are small.

When it comes energy efficiency measures (load shaving). Other studies have indicated that private customers in detached houses are able to save between 5-10 percent of their electricity consumption**.**

- **In Vattenfall's demand based tariff project,** the price was divided into two parts, one fixed cost and one depending on the power level. The result of the evaluation show that the customer found it hard to understand the idea of spread their consumption over time to reduce power peaks, compared to an overall reduction of consumption over a longer period. Many find it impossible to change their behaviour due to every day demands like work, school, training and other activities.
- **Elforsk report "Följa elpriset bättre; Prismodeller och styrteknik"**
  Two field studies were conducted. In the first field study, households with waterborne electric heating were subjected to remotely manage direct load control. The result of the study shows that it is possible to automatically reduce load by lowering temperatures during peak load periods without causing discomfort for the families. Indirectly controlled customers were very active.
- **Elforsks report "Elförbrukningens karaktär vid kall väderlek"** shows that over 10 percent are planning to implement changes in their heating system in the coming year of which over half are planning to install a heat pump. In the short-term the households use both additional bio fuel and lower indoor temperatures to reduce energy use.

Nearly 30 percent of households indicate that they will act if the electricity price was varying hourly during the day. And that would influence their use of electricity.

- **A family contest** that Vattenfall in Finland had on the web was very successful both in the way that the families that were participating did a good job and saved a lot of electricity. But it also gave a lot of good publicity both on the web and in the newspapers. To get positive media around the tests this could be one way of achieving that.

4.3.1 Private and SME Demand Participation

4.3.1.1 Potential for Demand Participation for private and SME

DP potential for hourly spot prices (Sales) current grid tariffs (DSO)

Load shaving for heating and boilers, is expected be the major part affecting the total cost for electricity. It is expected to be in the order of 3-5% of the total consumption. For a rather large private consumer with a yearly consumption of 20.000 kWh it will thus be about 600-1.000 kWh. The saving for the customer will be in the order or 1000 SEK per year.

Load shifting for both heating/boilers and appliances will be a lot smaller part, less than 1% of the total consumption. Since the price difference between hours is rather small, about 0-20 öre per kWh, the saving will be 50-100 SEK per year. The major part of the savings comes from extreme price peaks, rather than a potential for shifting on regular basis. The price difference at extreme peaks can be in the order of several SEK.

Some preliminary results from the “Peak shaving” project confirms the assumptions above. The project has studied historical hourly consumption data from about 45 actual customers. The project has evaluated the potential for load shifting and shaving in kWh for heating, boilers and appliances. The project has also estimated the cost savings. The price model used is that the customers will have hourly Nordpool spot prices for electricity and current grid tariffs. The result is that the average yearly potential for load shaving is about 500 SEK. About 100 SEK comes from lower cost for the tariffs, about 200 SEK from lower cost for electricity and about 200 SEK from reduction of taxes and certificates. Reduction from load shifting is about 100 SEK. So in total, the average customer will save 600 SEK per year.

This indicates that there is a clear risk that the contribution for load shifting from private customers is very small.

Nordpool spot (Sales) and flexible time tariff (DSO) for the main part of the tests
The grid tariffs constructions that have been discussed within the pre-study is a more flexible time tariff, a power tariff and a tariff connected to the wind production. The experience from the Demand based tariff project in Sweden shows that it is very difficult for the customers to understand what a power tariff is. Therefore the flexible time tariff is the alternative that is selected for the main part of the tests. The flexible time tariff has also high prices during the day between 07.00 – 11.00 and 16.00 – 20.00. This tariff has also a bigger difference between high and low price compared to the current time tariff. The current time tariff is described in the appendix.
.
The price model for electricity that will be tested is based on the hourly spot prices from Nordpool. There are also other price models that can be tested after further evaluation like “Fixed price with a right of return” that was tested in the Elforsk field study.

Reinforced price signals (Sales) and peak power tariffs (DSO) for a limited number of customers
In additions to spot prices, the proposal for SGG is to also investigate price signals with a stronger coupling to the wind power production in relation to the local consumption – i.e. reinforced price signals. Reinforced price signals will give more volatile prices and customers will thus get a stronger economical incentive to follow the wind power production. More studies are needed around reinforced price signals, e.g. if there is a need to have a separate price area for Gotland, getting feedback from customer focus groups, how to calculate the reinforced prices, implement systems to handle and send price signals. Implementing reinforced price signals will remain as much as possible within existing regulation and only getting exceptions from existing regulations where necessary and possible. Where existing regulations turns out to be a serious barrier against cost-effective integration of renewable electricity production, this will be reported to the relevant authority.

The customers will probably not want to take to much risk in trying new market prices. Therefore, the customers participating will need some type of "guarantee" that their total cost will not be higher than "normal". This will also increase the risk for the sales company offering reinforced price signals.

Also grid tariffs with a direct coupling to the peak power consumption(s) during a month will also be further investigated. Such a tariff will be similar to the tariffs used for customers at 80A and above. Preliminary results from the peak shaving project show that peak power tariff will give higher incentives to the customers for cost savings.

Further evaluation is needed for both reinforced price signals and peak power tariffs, including the number of customers who will be invited to participate.

4.3.1.2 Customer sub-segments for private and SME

There are two main customer segments identified that are proposed to be involved in SGG. The customer segments are

- Houses with some kind of electric heating component consuming more than 8000 KWh per year.
- Farmers (mostly dairy farmers)

The selection of these two segments is based on the following facts

- They are the two segments with the largest consumption per customer within the Privat&SME group
- They have the best potential to act on DP signals due to their heating system
- They probably have a higher incentive to save energy/money due to higher consumption/cost

The market test will be divided into sub pilots with some different characteristics depending on the customer type and heating system:

- **Pilot A-B : Private detached houses, >8 MWh/year, direct electric heating**
- **Pilot C-D :Private detached houses, >8 MWh/year, waterborne electric heating**
- **Pilot E : Farmers, steering of grain mill**

All private customers that buy both distribution and electricity from GEAB (whole GEAB customer) on Gotland in the consumption segment 8-40 MWh are invited to participate in order to get a large enough base for analysis. We estimate that 20% of the invited customers will participate in the market test.

Table 2: Total available number of potential pilot customers.

	Källunge/ Bäcks	Blåelds- vägen	Slåtter- gatan	Rest	Totals	Min 10%	Est. 20%
Houses 8-40 MWh	770+850	100	100	9680	11500[2]	1150	2300
Farmers (small)	<100	-	-	~900	1000	100	200
Other SME	TBD	-	-	TBD	TBD		

Based on discussions with GEAB they have identified two smaller house areas with about 100 households each that would be especially suitable for testing since they don't have any district heating. These areas (Blåeldsvägen and Slåttergatan) are concentrated and are situated quite close to GEAB's office, which makes it possible to give this customer group a more personal treatment during the test.

Prosumers

The current situation for prosumers up to 43,5 kW on Gotland is that there is only one solar panel installed. One small-scale windmill will be installed by the end of 2011.

If market tests with prosumers are to be included in SGG, then more activities are needed to promote more customers to become prosumers.

4.3.1.3 Design of market tests for private & SME

The aim is that all pilot groups can lower their costs by working with load shifting, shaving and energy efficiency.

- All customers will have new grid tariffs and price models for electricity during the test.
- All customers will have at least one controllable electricity product (heating or water boiler).
- All customers will have tools for visualisation and control.

Pilot A - Direct electric heating – Blåeldsvägen (Visby)

The objective is to test DP on customers with direct heating systems. The customers will get more detailed information about their consumption and receive price signals as well as personal advise from GEAB/Vattenfall. The customers can then take active actions to change their consumption in an optimal way. The potential product to control is the water boiler. This local group can get special treatment as direct meetings and is therefore also a potential group for the more complex reinforced price signals.

Pilot B - Direct electric heating, rest of Gotland

Same as Pilot A on the rest of Gotland but without reinforced price signals and local activities.

[2] Some of these customers can have a large consumption without having electric heating and that will have an impact on how many customers that can participate in the market tests

Pilot C - Waterborne electric heating, Slåttergatan (Visby)

The objective is to test DP for private customers with waterborne electric heating systems focusing on direct control of their heating system. They will still need consumption information and signals when the steering has taken place. . This local group can get special treatment as direct meetings and is therefore also a potential group for the more complex reinforced price signals.

Pilot D - Waterborne electric heating, rest of Gotland

Same as Pilot C on the rest of Gotland but without reinforced price signals and local activities.

Table 3: Overview design of market tests – Private

	Direct heating		**Waterborne electric heating**	
	Pilot A **Blåeldsvägen**	**Pilot B Remaining Gotland**	**Pilot C** **Slåttergatan**	**Pilot D Remaining Gotland**
Grid tariff[3]	Flexible time tariff/ peak power tariff	Flexible time tariff	Flexible time tariff/ peak power tariff	Flexible time tariff
Price model electricity[4]	Spot-prices/ reinforced price signals	Spot-prices	Spot-prices/ reinforced price signals	Spot-prices
Direct steering water heater[5]	X	X		
Direct steering electricity heating			X	X
Visualization on pc or display	X	X	X	X
Price signals and prognosis	X	X	X	
Personal energy efficiency advice	Phone, mail and meetings	Phone and mail	Phone, mail and meetings	mail
Compare with neighbours	X		X	
Participate in web competition	X		X	

Pilot E - SME customers/Farmers

The farmers seem to be the best potential group for a market test in the SME segment. They seem to have at least one potentially good appliance for demand response. That is the grain mill (Swe:"säderskvarn"), a machine used for grinding grain for animal food. These mills have a power between 7 and11 kW. The time of use could be shifted to another time of the day (but probably not to other days).

[3] Grid tariffs needs further investigations before final decision
[4] Price models needs further investigations before final decision
[5] Can be voluntary

Apart from the control of the grain mill the farmers can also work with energy control of heating in their residential house (there is usually no heating in the cowshed). Finally they could also engage in general energy efficiency to lower their total consumption of electricity.

Table 4: Overview of market tests - SME/Farmers

	Pilot E: Farmers
Grid tariff[6]	Flexible time tariff
Price model electricity[7]	Spot-prices/ reinforced price signals
Direct steering grain mill	X
Direct steering electricity heating[8]	X
Visualization on pc or display	X
Price signals and prognosis	X
Personal energy efficiency advice	Phone and mail

Preparations needed before the market pilot starts

A much deeper analysis is needed before final decision about what price models/tariffs that should be tested both from the customer point of view and from a Sales and Distribution perspective. Both these discussions are already ongoing and will be continued the upcoming period.

Tests in customer focus groups on Gotland are needed before the customers are invited to participate in the pilot. How the agreements are worked out in detail will also be tested on customers beforehand.

When it comes to the need of technical equipments, see Chapter 4. The hypothesis is that the customers do not have a willingness to pay for the equipment before they understand how to use it and what they will gain from it. The customer agreement can state that the customer have a possibility to buy the equipment after a year.

4.3.1.4 Evaluation of market tests for private & SME

This kind of market pilots were the customers themselves decide whether they shall participate or not can never be scaled up to the whole population because there is a self selection factor that influence the result. A conclusion based on the participants will not give an answer about what will happen if the whole Gotland was involved in the market test, but it will give a good result about this specific group. Still it is of great importance that there are many participants because then it is possible to say that if 20% of the inhabitants of Gotland is more active on steering their energy use and lower their consumption the conclusions about how that can effect the total consumption on Gotland is relevant.

Included in the market pilots there are also two smaller local groups in Visby; one with direct heating and one with waterborne electric heating systems. These two groups will get more information, advice and more attention; perhaps also participate in a competition. The hypothesis is that the customers get more active if they get more knowledge and attention. This setup gives a possibility to test that hypothesis.

[6] Grid tariffs needs further investigations before final decision
[7] Price models needs further investigations before final decision
[8] Can be voluntary

Methods

The evaluation methods used will be both qualitative and quantitative.

Quantitative measurements:

- The energy saving/shifting potential is measured by adding reference groups and historical consumption baselines for comparison.
- The consumption of the customers participating in the market pilots will be compared with their earlier consumption and with consumptions in the reference groups. All values must be corrected with temperature changes between the years.

Qualitative measurements:

- Before the customer gets the invitation to participate in the pilot all offers will be tested in customer focus groups.
- The qualitative evaluation will consist of both deep interviews and questionnaire surveys. The first interviews will be conducted after 3 month for a selected part of the participants. That survey can indicate that the customers need more information. After 6 months all participants will have a questionnaire.
- At the end of the market tests there will be deep interviews, customer focus groups and a survey send out to all participants.

4.3.2 Commercial & Industries Demand Participation

4.3.2.1 Potential for Demand Participation for Commercial & Industry

Different types of commercial customers with an annual consumption above 200 MWh connected to the Källunge and Bäcks substations are addressed for the industrial pilot project. In addition to this a couple of larger process industries like Cementa will be addressed even though they are situated on another part of Gotland.

- With the selected consumers of in Källunge and Bäcks the test will roughly cover 70 % of the total consumption with an average load of ~1MW . With the assumption that 5 to 10%, of that load depending on the price difference, is shaveable or shiftable, which will give a balancing capacity corresponding to 3 to 7% of the total industrial load.
- The energy saving potential is usually in the range of 10 -20% with an increased awareness and by optimization of the large energy consuming equipments. Some customers already participate in different energy efficiency programs, e.g. “energipengen” run by the community of Gotland.
- For Cementa, the by far biggest consumer on Gotland, the situation is quite different. Approximately half their consumption comes from mills that are very sensitive to energy prices and are already today mainly operated during night time. The mill load is in the range of 20MW and is there for the biggest potential for load shifting on Gotland.

4.3.2.2 Customer sub-segments for Commercial & Industry

C&I customers are divided into four segments, according to their kind of production activity and their similarity in DP perspective.

Heavy industries

This segment is composed by industries producing cement or asphalt. Some of them already have monitors to visualize prices or manual systems to manage electricity consumption. The large use of machines graining and moving materials has a big potential to shifting load and to reduce energy consumption with modern control equipment.

Food industry

The main part of these industries is vegetable and milk producers. Food industry often has a high base load. For most of the food producers, cleaning process, refrigeration and freezing systems account for as much as 80% of the industries 'energy bill. This means that by controlling temperature of these processes it is possible to move consumption to reduce energy costs. Even if the customer already has taken energy efficiency measures, it should be possible to steer the consumption to avoid peaks and thereby reduce the cost for grid the connection since it is based on a power tariff.

Agricultural industry

Agricultural industry like milk producers uses robots for milking their cows. They can not steer the load since both feeding of the animals and milking is a continuous process during a 24-hour period. One task that could be optimized based on electricity prices during a 24-hour period is grinding grain for feeding of the animals. Also fertilizing could be optimized. Other examples of what electricity is used for are: several houses on the farm, large cooler for vegetables, dryers for grain, egg production with ventilation and feeding machines.

Other industries

In this segment remaining industries are included, usually using ventilation and pumps in their production cycle. Also for these industries, many are already active in energy efficiency programs. E.g. Prevab has large energy consumption for cooling and should be able to reduce cost by more efficient control and steering.

Facilities

Facilities are excluded from pilots because in Gotland they usually have district heating; in addition the electrical consumption of customers composing this segment is less than that of others C&I customers. Main characteristics of the bigger commercial and industrial customers in Källunge and Bäcks composing segments have been summarized.

4.3.2.3 Design of the market tests for Commercial & Industry

The common objective of market tests is to test DP for commercial and industrial customers and how a suitable control system will affect energy efficiency. The goal is to get an understanding on how much consumption is controllable and to explore possibility to improve energy efficiency. C&I customers will also get an overall advice on consumption optimization and available control systems suitable for their needs.

Contacted C&I customers are all interested in being involved in pilots about energy efficiency and demand response in order to save money and reduce energy consumption. Some of them are already involved in energy efficiency programs and already use price signals manually, in order to control their consumption according to energy prices. .The interviews will start with one customer from each industry category that already has energy efficiency equipments and/or is involved in energy efficiency programs. They will help to obtain preliminary information about potential load shifting and energy savings and get further help in their energy efficiency programs..

Based on the knowledge from the initial interviews and consultancies, the program will continue with the rest of selected industries. They will receive advices about automation equipments that could help them to be more energy efficient. They will also be invited to be a part of new price models, based on hourly price signals to manage their load.

Technical systems for the pilots

The ABB System 800xA Extended Automation permits to adjust the settings for the most efficient operation possible. In addition, it can automatically help industries to disconnect processes with low priority when the supply of electricity needs to be cut down. Into the control system it is possible to bring in the price level system in order to optimize process according to energy costs. ABB experts will meet C&I customers in Gotland in order to find out their potential about energy efficiency system and process optimization. Customers will receive personal energy efficiency consultancies from ABB. ABB will produce customer specific proposals to each individual customer. Customized solutions will be based on the overall System 800XA Extended Automation and different tools (more detail information is found in Appendix 4):

- Asset Optimization: a plant asset management solution that presents real-time information seamlessly and in the proper context to operations, maintenance, engineering, and management.
- Production Management: integrates all manufacturing systems, providing the real-time visibility, execution, tracking, reporting, and optimizing of manufacturing processes. This results in decreasing costs through better production scheduling, execution and management, and increases revenues through improved customer service and product quality, increasing profits and enhanced shareholder value.
- cpmPlus Energy Manager: helps industry customers/prosumers , monitor, manage and optimize their energy usage for maximum efficiency and cost savings based on spot market prices. Different industries have different potentials according to production processes and controllable consumption. Therefore, three pilots will be tested on Gotland according to the C&I customers segments considered:

Pilot F: Heavy industries

- Production processes of cement or asphalt industries, use mainly drives and pumps that thanks to a frequency control give a huge potential in energy saving. Depending on the utilization level they will also be a potential for load shifting
- By applying suitable control system they can save up to 20% of energy.

Pilot G: Agricultural industries

- Cooling represent the most important process and more energy consuming process.
- Cleaning process represents a possibility to shift load by using hot water storage and optimize the temperature within the allowed range against energy prices.
- Grinding process is only done temporary an easily controllable according to energy prices.

Pilot H: Food industries

- Cooling and freezing represent most important phases for these industries and in the same time they are also more expensive processes in terms of energy consumption. By combining heating and cooling system it will be possible to reduce and shift load.
- Processes using compressed air, like packaging, could be managed by shifting energy consumption to cheaper time by installing larger tanks for compressed air.
- Cleaning process represent a possibility to shift load by using hot water storage and optimize the temperature within the allowed range against energy prices.

Pilot I: Other industries

- District heating with large heat pumps and even bigger electrical heaters have a large potential for demand participation specially if some kind of hot water storage is installed.
- Ventilation and pumps are mainly used by these industries. Also in this case energy can be saved by using a frequency control system for fans and pumps.

4.3.2.4 Evaluation of market tests for Commercial & Industry

The evaluation of the pilots for C&I customers will use both quantitative and qualitative methods:

Quantitative methods:

- Data coming from C&I customers during market tests will be compared with their earlier data referred to a previous period.

Qualitative evaluation will be run in two different steps:

- A first evaluation will be run after 3 months from the start of pilot through a deep interview with customers. The aim will be verify the status of control systems implementation, if they have problems or suggestions to improve systems. In addition it will be possible to check if customers are active on DP and on energy efficiency in order to understand if they eventually need more information.
- A second evaluation will be run at the end of the market test thanks to deep interviews and a more general questionnaire. The aim will be to gather data about DP and energy efficiency in order to analyze results and make preliminary conclusions.

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4.3.3 Aggregator

There are several proposals for different aggregator roles where an aggregator could add value. However, due to the current market and technical conditions in SGG there is not obvious that there are any strong commercial drivers for an aggregator role. Therefore, more and deeper studies are needed after the pre-study in order to propose how to handle the aggregator role. It could for example be that you simulate some aggregator role with only a few customers involved.

For more details about the aggregator roles briefly evaluated in the pre-study, see appendix.

4.4 Information and Communication Technologies

The information and communication network at Gotland, extended and updated to meet new requirements, will be tested and evaluated, both when it comes to the support for the Smart Grids functions and for the IT security functionality.

The communication and integration of systems for the different parts of the Smart Grid Gotland project will be verified within each specific area as part of the installation phase. In addition the ICT part shall include separate security testing to secure that security requirements are fulfilled by the Smart Grid solutions and components.

Test and evaluation during the operation of the implemented systems include validation of the ICT communication and IT security solutions implemented in Smart Grid Gotland. The evaluation shall be done after six months operation of the complete installation.

The objectives include:

- Evaluate the ICT solutions.
- Evaluate the IT security solutions and established processes.
- Validate the complete solution through an audit of the installations.

5 TECHNICAL DEVELOPMENT

In this chapter technical development needed to demonstrate Smart Grid functionalities and to perform above described test and demonstrations are presented. The technical description of these parts is further presented in technical documentation that is enclosed as appendices to this main pre-study report, which is an abridged version of these technical base documents.

5.1 Rural Grid

Rural grid development has been divided in five parts:

- Smart Substation
- Smart rural feeder (feeder automation)
- Smart LV network
- Smart Grid planning tools
- Smart Grid monitoring and maintenance

The project part representing rural grid development aims to develop and establish a grid concept that is open and prepared for integration and interaction with renewable sources of energy and demand response with regards to, e.g.:

- Bidirectional power flows
- Intermittent generation and island operation
- Demand response and peak capacity reduction
- LV monitoring and control, including advanced metering and power quality
- Impact on CAPEX and OPEX

The scope of rural grid development includes:

- Development and delivery of a new Smart Grid substation (Bäcks) with state-of-the-art equipment and systems. The substation shall be environmental friendly and support required new features for the Smart Grid. The concept shall allow testing of new functions related to the supervision and control of the Smart Grid.
- Design and delivery of products for modernization of a second substation (Källunge) connected to the same Smart Grid. The upgraded substation shall support control and testing of connected Distributed Energy Resources (DERs), voltage control, power quality and energy storage.
- Installation and testing of the rural grid concept called “Zone concept” in the existing 10 kV grid.
- Extended functionality required for Smart Grid, applied in the LV distribution network through advanced metering and metering data collection in combination with integration of Automatic Meter Management (AMM) technology and network technology.
- New monitoring facilities and communication required for supervisory of the Smart Grid and for improvement of maintenance planning and execution.

5.1.1 Implementation

The two substations Bäcks and Källunge are located at each side of the rural grid area proposed for the pilot installation. The 10 kV rural grid is in normal operation divided in two parts, one supplied from Bäcks and the other from Källunge. In special situations it will be possible to feed most of the grid from one of the substations.

5.1.1.1 Smart substations

Both substations, in Bäcks and Källunge, consists of one 70 kV switchgear, one transformer 70/10 kV, one 10 kV switchgear and a substation automation system. Additionally to these parts the Bäcks substation is equipped with a 70 kV feeder and a transformer connected to the HVDC Light link to southern Gotland. The substation Källunge will include a 10 kV connection to the Static Var

Compensator (SVC) system that is extended with battery storage. This is described in a separate chapter below.

The pilot project includes a complete reconstruction of the substation Bäcks and a replacement of the 10 kV switchgear and the substation automation system in the substation Källunge.

70 kV switchgear (substation Bäcks)

The existing 70 kV switchgear is traditional outdoor switchgear with circuit breakers and disconnectors. It is proposed to build the new substation as an indoor solution using Disconnecting Circuit Breakers (DCB) in the 70 kV part. The switchgear is of air-insulate type but built into the same building as the rest of the equipment.

An indoor solution has advantages like:

- Better climate sustainability
- Better protection from external damage, e.g.
    - Thunderstorm
    - Animals (e.g. birds)
    - Sabotage
- Less maintenance and extended length of life for the equipment
- Better match the surrounding environment in urban or suburban locations

The proposed switchgear arrangement is single busbar and feeders with DCB. With the DCB there is no real need for traditional disconnectors and less need for double busbar. The arrangement includes much less equipment and the equipment used will have lower Mean Time Between Failure (MTBF) values, meaning that the requirement of maintenance can be drastically reduced.

10 kV switchgear

The 10 kV medium voltage switchgears will be modern type indoor switchgears using withdraw able type of circuit breakers. The arrangement is an ordinary single bus with no bus sections. The switchgear will be equipped with:

- 1 incoming feeder, connected to the 70/10 kV transformer
- 1 metering feeder, for measuring of busbar voltage
- 1 auxiliary supply feeder, with 10/0,4 kV transf. for power supply to the substation
- Several outgoing feeders, for supply to the rural grid
- 1 capacitor feeder
- 1 feeder for SVC and battery storage (in Källunge)

The switchgear type will be UniGear, which is medium voltage switchgear with metal enclosure for indoor installations without SF6 gas insulation and withdraw able vacuum circuit breakers.

Transformer

A dry type transformer may be used of environmental reasons, i.e. no risk for oil leakage. It will be investigated if this type of transformer can be installed in Bäcks or in Källunge. It has been planned to replace the transformer in Källunge, but if the dry transformer suites the indoor solution and the required size for Bäcks this location will be preferred. The aim is to find the best possible solution considering the environmental aspects in the substation of Bäcks.

The transformer should be equipped with the integrated transformer electronic control & monitoring device, TEC. The TEC have advantages such as monitoring of values to be used for asset management and maintenance planning but also for advanced controlling of cooling system. The advanced control will keep the transformer at a more or less constant temperature for minimizing the ageing of the device. It has to be investigated how the TEC will best suit the dry type transformer.

A possibility to be able to run the transformer with a planned and controlled level of overload in special situations is an important feature that will be supported by the TEC. The Smart Grid, with intermittent power generation and alternating power flow may put higher demands of short overload capability of the transformers, especially in the actual case of using one 70/10 kV transformer in the substations.

Auxiliary power supply system

The auxiliary power supply of the substations consists of a 400/230V AC distribution system and an 110V DC system, both supplied from the auxiliary power transformer. The DC system will be supplied via AC/DC converter and with power back-up from station battery.

Depending on the decision of redundant protection & control system in Bäcks, the 110 V DC system in Bäcks may be of redundant type, meaning that it will be built as two systems each with AC/DC converter and battery.

Of environmental reasons it is desirable to use batteries of Lithium-ion type. Due to the less experience of this type of battery in the context it would not be recommendable to use the Li-ion type for both batteries in the substation. However, the Li-ion type battery has earlier been tested in operation by Vattenfall and it can be recommended for one of the two redundant systems.

5.1.1.2 Smart rural feeder

Between the two substations Bäcks and Källunge a rural 10 kV grid with infeed from both substations is located. This 10 kV distribution network shall be evaluated for installation of the zone concept.

Zone concept, description

The Zone concept provides a model for dividing distribution networks into zones, separated by active and intelligent components, in order to handle fault situations in an optimal way. Some features of the concept are:

- As few consumers as possible will be affected of a fault in the grid
- “Rolling blackout” and load calculation of connected areas will be supported
- Power restoration of the grid can managed faster and more effective, in many cases will the concept be “self healing”
- Personnel need will be minimized, e.g. for fast reconnection in the grid.

Additionally, the increased use of distributed energy resources complicates the network operation but it also provides additional means to secure the power supply. In such a situation the zone concept will provide a useful model for planning and upgrading of distribution networks.

The zones in the concept are separated by zone dividers with protection and breaking/reclosing or only disconnecting capabilities. All zone dividers are provided with facilities for remote communication for transfer of status indications, control commands, measurements, etc. required by the application. Depending on the capability of the zone divider equipment the zone on the downside is either a protection zone or a control zone. Today the ongoing increase of distributed energy resources put special demands on the flexibility of the equipment functionality and adaptability.

For improved fault detection in the 10 kV grid will a third party on-line feeder monitoring system be installed and tested at some feeders. The monitoring system will measuring power flow in any direction of the line and make it possible to fast and selective isolate any faulty part, see Figure 13.

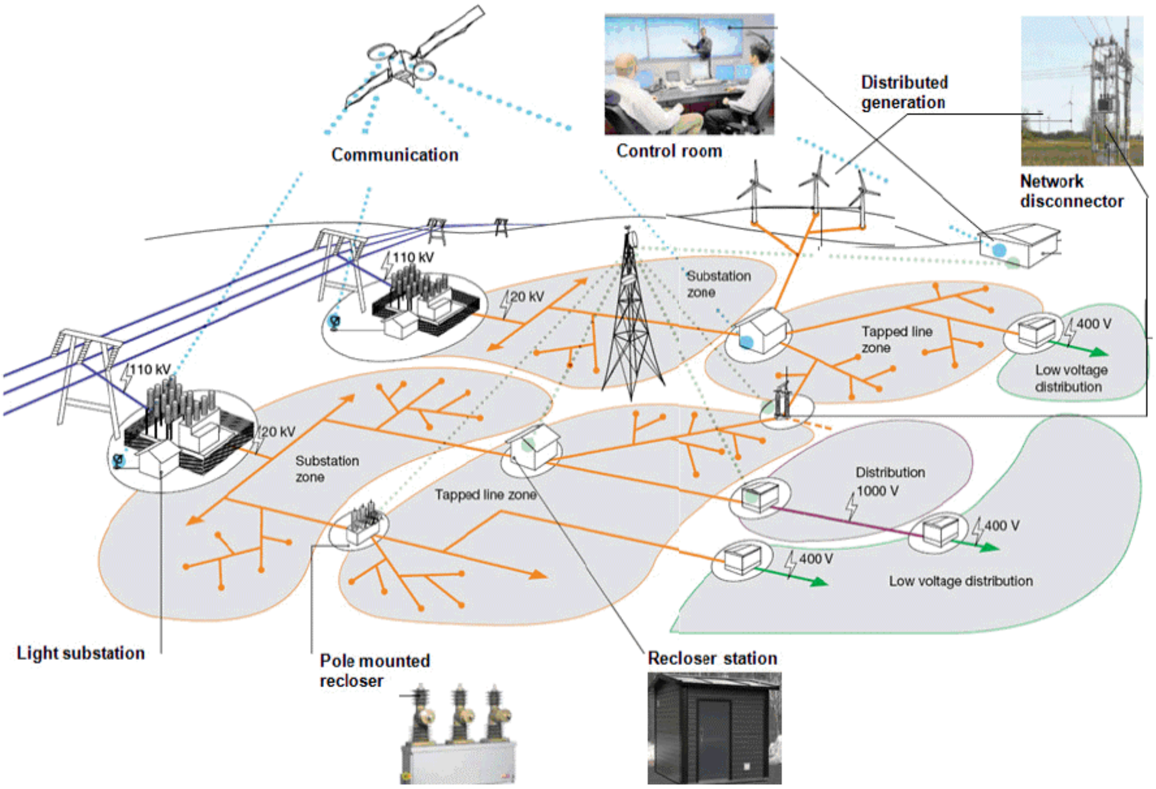

Figure 13: Zone system overview.

Circuit breakers and disconnectors are probably the most essential components in the distribution network. However, based on the need to secure the supply and reduce losses there is also an increasing use of distributed compensation equipment. Communication with an upper level system is required in order to gain the full advantage of the automation.

Alternatively to the recloser, using the circuit breaker, a Load-break switch Station may be used. The load-break capabilities are especially useful in network reconfiguration situations. As the load-break switch station is provided with the same secondary equipment as the recloser station extensive measurements and control capabilities are available, see Figure 14.

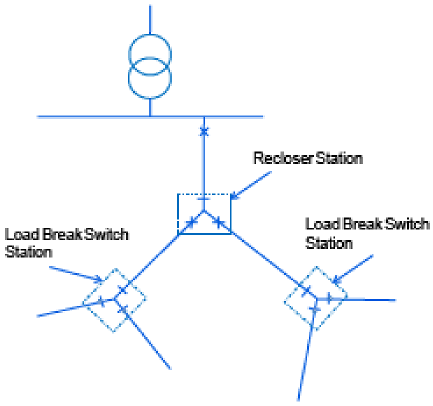

Figure 14: Recloser and circuit breaker solution.

Zone concept control (relation to DMS and SA system)

The latest development of systems and communication has made it possible to get an active overview and control of the whole distribution network from the control centre using improved DMS functionality. It is also possible to locate such functionality to the substation.

A system which takes into account the existing loads at various locations and the supply capability of alternative network configurations makes it possible to implement fast, fully automatic fault localization, fault isolation, network reconfiguration and power restoration functionality, i.e. to create a self-healing power distribution network.

In the project it will be studied and decided if some of the functions shall be included in the substation automation system or if the complete functionality should be included in the central SCADA system of Gotland.

When introducing new distributed devices in the 10 kV network considerations to the maintenance aspect has to be taken. The use of device monitoring and information to AMS shall be evaluated.

Communication
An important part of the zone concept is the communication, as it is essential to know the status of the zone divider equipment and to control it. In the selection of the communication methods not only communication features but also availability and security issues have to be addressed.

The development of public wireless network has become feasible to arrange communication to most of the nodes in a distribution network. However in the actual grid a wireless communication has been used for control of the existing disconnectors. It will be evaluated in the project if the existing wireless network will be usable for the zone concept or if the communication has to be improved.

5.1.1.3 Smart LV network

The existing LV network is not monitored or controlled remotely. However existing AMR technology can be used to provide much more information on power quality and on LV network status and condition that will be advantageous for improved operation and control of the system. Each AMR energy meter is collecting and storing internally a lot of parameters. This is information about energy consumption, and relevant information on actual LV network conditions regarding, voltage, frequency, load, flicker and various kinds of alarms in regard to the network status. Each meter manufacturer has its own meter design and provides different facilities included in the meter and the choice of manufacturer thereby also sets limitations to the possibilities in the area of quality of supply information. Some meters have possibilities to connect and disconnect appliances beyond the meter at the consumer's premises. This opens up possibilities for new services to be provided by the network companies.

The use of data collected by the existing or future AMR equipment located at customer sites coupled with new equipment in the secondary substations, enable the development of operational centres operating the LV network with basically the same options as the MV network.

This in turn:

- Simplifies the connections of small-scaled distributed generation.
- Allows the available extended power quality information to serve as input to energy efficiency activities for DSO's and their customers (aggregators & retailers).
- Supports network operations and customer information exchanges, which thus have the potential to reduce the administrative (and technical) network losses.
- Helps validating the increased performance and functionality of the LV distribution networks, the increased utilization of DER, PHEV/EV and DP in existing LV network, as well as power quality improvements for the consumers.
- The task will harmonize the available technique to achieve the necessary function of monitoring and control the low voltage network. The network will then be an enabler for implementing renewable energy sources to this voltage level.
- The project will identify the final number of affected customers in the demonstration.

All collected data from customers and network needs to be handled and by combining the novel technologies for AMM and network there is a need to also optimize the system architecture at the back office. These R&D activities will evaluate this area and find future recommendations for the system support.

Meeting the mentioned objectives will result in a change in the functional performances of the network:

- Increased level of LV automation
- Capacity to implement demand participation
- Improved power quality
- More flexible connectivity of DER
- Enabling intelligent island mode in LV and MV network
- Possibility of using DC in LV networks
- Process information used for conditional based maintenance
- Harmonised communication solutions for the technical network and the AMM technology
- ICT architecture design principles leading to higher controllability and functionality

Metering and metering data acquisition

Although the AMM and AMI systems on Gotland have been adopted to smart metering devices since many years and the equipment has availability to conduct hourly metering this may not be sufficient for the targets for the project, e.g. the pilots regarding demand participation, small scale and micro generation, alternative tariff structures, etc, and monitoring and control of LV networks, so-called "last-mile-SCADA".

For the purpose of LV network monitoring and control it is anticipated point-to-point communication with the meters will be necessary in order to fulfil demands and possibilities for regarding enhanced control and monitoring functionalities (approx. 2800 meters), advanced metering and close to real-time customer energy management (anticipated approx 2000 meters). Presently many meters are of early dates, approx. 10 years old, why it would be advantageous to replace these meters with modern equipment for the purpose of the project, e.g. to provide data for reactive power metering, various kinds of alarms, power quality and to facilitate customer energy and demand management. Additionally many existing meters are communicating via concentrators and will not be able to perform metering data delivery in anything near real-time. Nor will it be possible to establish communication to these meters from the control equipment at the control centre.

Hence the metering equipment and metering data acquisition system have to be replaced by more advanced devices to render possible to perform anticipated functionalities. Point-to-point communication with meters will also be implemented to realise the possibility to receive detailed data in near real-time and also for sending signals in order to check status of meter and supply. The old metering data acquisition system has to be replaced by a modern system capable of processing and delivering near real-time metering values and other data necessary for monitoring and control of the LV network in near real-time. It would be advantageous to select a metering data acquisition system similar to that selected for Vattenfall's other Swedish markets in order to streamline and simplify Vattenfall's metering data collection, data storage and data processing. Coordinating procedures for procurement and implementation of new meters and metering data acquisition system with similar activities elsewhere within Vattenfall would most likely limit necessary work and costs in regard to adaptation of meters of various generations to the metering data acquisition system. However final decisions on selection of manufacturers will not be taken until the most beneficial technical solutions for the project are determined in the initial phases of the main project. In any case, tests for adaptation of new metering data acquisition system and data collection interfaces for various kinds of meters will have to precede the implementation phase. Especially is this the case, should new meters be mixed with old meters in the same network section, which would require additional test activities.

EV/PHEV charging

Furthermore new equipment for charging of EVs/PHEVs will be installed in order to be able to meet expected future demands for EV/PHEV utilisation as well as to facilitate use of excess wind power during time periods when the increased wind power implementations generate surplus of power. Monitoring and control of wind power generation for coordinating EV/PHEV charging during selected time periods will be facilitated by the Smart Grid functionality. Charging poles for EVs/PHEVs could be implemented at selected sites where found suitable, e.g. at shopping centres, at GEAB’s new office, at commuter parking lots adjacent to central Visby and at meeting and exhibition places such as Almedalen.

Although EV/PHEV charging on a lager scale may pose problems to the network, limited implementations suggested for this project, i.e. 10-20 charging poles relatively evenly distributed in the network, may not present any major difficulties to the distribution network system in regard to overload of network or transformers. However, should introduction of EV/PHEV charging poles on a massive scale be imminent including residential areas as well as public sites, detailed studies for the loading and design of the entire network on Gotland would be suggested. This would be especially essential should fast charging be considered that may result in relatively high amperage during the duration of charging. This will probably not pose any severe problems at limited implementation at the public sites as suggested above since these will be new installations and therefore designed accordingly.

Considerations need to be taken to the charging poles installations should dedicated payment system be required. For the limited number of charging poles presently existing at Almedalen at Visby, the EV/PHEV charging is free of charge. However it is not anticipated this will be the case if a larger number of charging poles are to be introduced at public sites. Consequently payment and metering system including properly designed data communication should be considered for public utilisation of charging poles and adequate payment procedure for the amount of electricity consumed during charging. There are a number of solutions for metering, payment and data communication for public EV/PHEV charging existing on the market presently, why selection of appropriate system should become apparent as a fairly straightforward procedure. During the pre-study, a separate report has been compiled on EV/PHEV charging where investigations, suggestions and exemplifications are presented briefly in order to give a basic image of conceivable possibilities and feasible solutions.

5.1.1.4 Smart Grid Planning tools

By implementing and integrating ABB's SCADA system, Network manager, to the existing systems at GEAB, new possibilities for monitoring and control of the network will be possible. Beside the operative system it is planned to install a copy of the system applicable for testing of new Smart Grid functionality. Tools related to both these system will be involved in the planning and design of the extensions, as well as additional functionality, in the power grid.

The future Smart Grids will however be much more complex than today’s networks, which require a more complex model of the network in the tools. The supporting system tools and new system processes are vital factors for efficient operation and improved performance of the future networks.

For optimal use of the data received from the different measuring devices in the network a relevant modelling of the network and the power generation and distribution process have to be established in all systems processing the data.

Standardization and simplicity of the system architecture and set up are the main factors for achieving the anticipated functionality and performance and consequently also for success of the entire project.

Some of the transmitted data is of technical nature while other data is customer-oriented. Each of this data has its home/ownership in the common model and is utilized by the different systems. To achieve good quality this needs to be defined and integration has to be setup in the right way. The requirement of more real-time supervision and operations also requires clear information of the received values with regards to time and periodicity, transmission delay, etc. The amount of data flow and data rate is depending on if it is historical or real-time data.

The supporting systems described below will be involved in network planning and design. The exchange of information with the real (or estimated) grid will be handled in different sub-activities.

Meter data management system (MDMS)
The MDM system will be the major system to manage, store and calculate the data collected from customer sites and other measuring points in the power grid. The system will perform some of the calculations and simulations needed for monitoring and power flow control in the distribution network.

Metering data acquisition system
The metering data acquisition system is the main system tool for the transmission of data from customer sites to the Meter Data Management System (MDMS). The project will evaluate the possibility to use the collecting system for other data communication procedures as well, e.g. data required for demand response.

Network information system (NIS)
NIS will include the network topology of the actual network as well as any planned changes or extensions. Further to the “grid picture” the NIS will include and store data from the complete network. The project will be analysing how this data can be presented in the graphical user interface that is needed in the operational centre, the need for data storage and the definition of historical and real-time data.

Distribution management system (DMS)
The DMS functionality usually is a module in either the SCADA or the NIS system or in both. This “tool” is nevertheless the interface for the dispatcher in the operational centre and needs extra attention. The functionality is crucial and sets the possibility to monitor and take decisions for managing the network. It should be studied if Load Management and Fault Management in both MV and LV grids can be supported by the DMS.

Operation management system (OMS/SCADA)
The OMS has to be designed from the engineering tools related to network planning and design. The network model as well as data definitions must be in consistent with other systems and tools and have good correspondence with the actual network.

Asset Management system (AMS)
The asset management system is an essential tool in Smart Grid Monitoring and Maintenance (see description below). The asset management system requires specific information from the grid especially regarded to the products used in the distribution network and the substations.

Modelling, the multi aspect grid model
Any exchange or use of data in the systems shortly described above should be based on descriptions that are commonly understood by all systems. This means that data have to be related to a model that describes the real power network and all values represented by the measured values. The model shall preferably use standardized methodology and data definitions as far as possible. The model shall includes descriptions of the power network with regards to the different aspects required by the included systems but shall not use more complex descriptions than necessary. Some aspects that have to be considered in the model are:

- Power generation and load aspect
- Generation and load location aspect
- Operation aspect

- Product aspect
- Communication aspect
- Time aspect (general aspect)

5.1.1.5 Smart Grid Monitoring and Maintenance

In the smart monitoring system the relevant data should be reach in the top system level, but not all available data have be reported.

The providers of data in the monitoring system shall use relevant knowledge and information to draw conclusion and act after agreed rules and report relevant data upwards. Conclusions may be taken by the higher-level system or operators.

Communication from the monitoring devices (data providers) shall use the station LAN preferably with IEC61850 protocol.

Supervised devices (Power apparatuses)
Basically all HV and MV products can be supervised with some kind of monitoring device or with dedicated functions in the protection and control system. However, just a few products have special features or equipment with the purpose of condition monitoring. For some components in the grid the condition data may be calculated and delivered from the protection and control system I the substation.

The power transformer may be the device most commonly equipped with condition monitoring. The transformer is probably the most relevant device for monitoring because it is typically in constant operation and also a rather expensive device. In the Smart Grid the transformer may be specially stressed by big variation in load flow through it, caused by the wind power generation. This fact shall be especially studied e.g. by using values from the monitoring device.

The monitoring devices are typically designed and produced by the manufacturer of the component. Additional equipment and/or software for evaluation of the monitored data may be included as a complete monitoring system. Some data useful for the Asset management or maintenance planning may be available even in the case that no monitoring system is installed. In this case a selection of data already provided from the supervisory system shall be done in order to feed the AMS or planning systems.

Transformer monitoring
For condition monitoring of transformers is the TEC available. Further it should be noted that the TEC is a device not only intended for condition monitoring but also for controlling of the transformer.

The latest release of the electronic transformer monitoring system TEC also called “TEC smart” will be used in the project. The TEC smart is developed for integration in the transformer control panel located at the transformer, but will also act as an integrated part of the substation automation system using “open system” platform and communication based on IEC 61850 and web technology.

Special functionality developed (or in development) for the Smart grid will be tested and evaluated in the project. With the control facilities of the TEC smart e.g. fan control, can the transformer be better utilized with best compromises between high capacity, low losses and ageing.

The TEC will be able to present:

- Present status of the transformer, e.g. load, temperature, OLTC position, losses, etc noise level and cooling conditions for the transformer
- Prediction of e.g. condition based maintenance, overloading at different load, transformer losses at changes in load.
- Calculated winding hot-spot temperature and control the cooling system

The TEC has interfaces to:

- Station HMI (via IEC 61850 protocol)
- Remote SCADA HMI (via IEC 61850 protocol)
- Any PC connected to the LAN or WAN (via web interface)

Other monitoring devices

Circuit breaker monitoring
The circuit breaker is a very important device, as well, but the conditions for measuring of monitoring data are rather different from the transformer. The operation of the circuit breaker is mostly in stand-by and the prediction of faulty operation is difficult to give. The monitoring may however bring a “footprint” of all operations that can be used for comparison with the “perfect operation”. In the development of improved functionality, to be used in the project, is integration with the SA system based on IEC 61850 communication as a vital part.

Network monitoring
The protection and control system used in the substations and distributed in the power grid will additionally to functions as fault disconnection and restoration the system will also manage monitoring of power flow and measured load in feeders. The monitoring will act together with the DMS system to control the load situation in cables and distributed transformers, etc.

The system may be extended with “hot spot” temperature measurement devices in exposed power connection points in the power grid.

All incoming and outgoing feeders in the substation will be equipped with fault recording functionality, as an integrated part of the products in the Relion series. The fault recording will be distributed via the internal station LAN and the WAN to a central system for fault analysis required for planning of maintenance, etc in the grid. This functionality may be extended with integrated (or distributed equipment) for extended monitoring of the electrical power quality.

Monitoring of Auxiliary power supply
The batteries used for back-up power in the DC supply system are essential for secure operation of the substation. The batteries will be supervised by a modern monitoring system with the capability of capacity checking and present “per cell condition data”.

Monitoring of SA system and communication
The SA system, as described earlier, includes monitoring facilities of the software and the communication. The system will automatically inform about any fault or loss of information.

The aim to connect as many auxiliary systems and devices as possible with IEC 61850 based communication will improve the monitoring of the complete system because this communication includes strong features for self monitoring, such as quality attributes for all server-client messages or supervision of broadcast messages (GOOSE).

5.1.1.6 Maintenance

The aim of the project is to minimize the maintenance cost and prepare the system for Condition Based Maintenance (CBM) rather than scheduled maintenance. CBM requires a reliable system of monitoring and evaluation of received data. Other conditions for minimizing the cost of maintenance are to use products that can accept long periods of use between maintenance. This is most effective in typical substations where products of type switches, etc are very seldom operated but need to be in a “stand-by mode” for immediately and secure operation when required.

Fault clearance and repair is important activities related to maintenance. Well-tested and high quality products can minimize the risk of faults but a big part of the faults are caused by human mistakes. Human mistakes can be reduced by using clear and unambiguous information to the operator. Furthermore it is important to control that only the authorized person will have access for operations and other activities in the system. Especially design changes in the system have to be controlled and checked for release. In a modern numerical system can rules and integrated check functions or simulations be used to avoid not accepted activities. For application of this type of control is a standardized and pre-tested product, such as ABB Relion series, a prerequisite.

The control and protection concept supported by sufficient communication and modern tools will accept full remote access for maintenance. This access, restricted by the internal network security and operation quality restrictions, will be used in the Pilot installation to support local maintenance work.

Some action for reduction of maintenance cost with unchanged or improved operational quality of the system will be:

Primary system

- Use of DCB at 70 kV – no disconnectors that require short maintenance periods
- Indoor substation with low requirement for maintenance and guarding of the area
- Transformer monitoring and supervision with TEC for optimized use of the transformer and diagnostic for predicted maintenance

Secondary system

- Use of full numeric protection system, without components that will change set values due to ageing and integrated monitoring, meaning enlarged period between maintenance and simpler / atomized functional testing
- System built up by well-tested products and standardized communication interfaces (IEC 61850). Full system test procedures at delivery.
- Defined and certified procedure for any software changes in the system.

5.1.2 Dependencies

The Rural Grid Development part of the Smart Grid Gotland project has influences to as well as is dependent of basically all other parts of the project. The rural grid part represents the actual power grid that has to be supervised and controlled in order to realise the operation and functionality of other parts and in this respect the rural grid development is the backbone of the entire project. The grid provides the vital transportation of electric power from all power sources to the consumers; therefore the optimal usage of the systems included in rural grid development is highly essential for proper interactivity with related systems and equipment of the project.

It is important for any use of supervisory, monitoring and control system that the data exchanged with the distributed devices is distinctly and fully understandable by the user. The Smart Grid concept puts even higher requirements of unambiguously and clearly defined data in the exchange of information between the systems. It is also essential for the definition of the data to recognize if the data will be used according to an internal description (source definition) or if the data is described by the receiving system. The optimal situation is that a mutual definition is used. This will be obtained by as much as possible using international standards and common used praxis in the exchange of data. This is further discussed in the document in the appendices called Exchange of information in Smart Grid.

5.2 Distributed intermittent generation and network support

The purpose of the proposed Smart Grid Gotland activities within this part is to demonstrate the ability to support the introduction of wind production in a distribution system by introducing a reactive power compensator with energy storage giving the ability to control both active and reactive power injected into or retrieved from the system, another issue is to together with the wind power production at hand keep an island in the network running during an outage. There will also be communication and interaction with the support systems to make the control effective e.g. prognosis and load-flow calculation tools.

5.2.1 Description of work

The activities will be to describe and specify implementation of equipment and methods for increased utilisation of renewable energy sources (RES) for Smart Grid development by introducing a reactive power compensator with energy storage (batteries) into the system. In combination with new substation equipment and new control facilities for improved monitoring and controllability of the LV/MV network the development will enable network capacity increase for hosting a larger number of RES and facilitate control of electricity load by control of active and reactive power. This will in turn:

- Enable extended connection of distributed generation i.e. wind power
- Allow for increased reliability of network by allowing for islanding
- Support network operation and voltage control increasing quality of supply.
- Combined with demand participation and wind power control increase the over all efficiency of the network utilisation and energy use in all three points above

In the work both installation of hardware and software development is included.

The activities will demonstrate the following:

- Improved voltage control, voltage collapse mitigation, system stability and limitation of harmonics caused by windmill converters by use of reactive power compensation.
- Smoothening wind power dynamics and support of frequency regulation by use of a reactive power compensator combined with large-scale batteries.
- (Intelligent) islanding schemes.
- Active support for load flow control and interchange with external fed power for network support.

5.2.2 Description of benefits

The Smart Grid Gotland reactive power compensator and energy storage demonstration will be able to represent Smart Grid development for increased network hosting capacity for wind power and utilisation of renewable energy resources (RES), and the consumers' integrated Demand Participation (DP). At the same time the Smart Grid development will achieve increased reliability and quality of power supply and improved network operation efficiency, necessary for paving way for reduced costs for network investments and losses.

The DynaPeaQ system will provide economic, environmental and social benefits as described below.

Economic

- Small-scale demonstration of applications with economic benefits: the DynaPeaQ system will demonstrate the technical feasibility of storage applications that may not be economically feasible at present but that will become viable with future developments, such as:
    - Increased penetration of variable renewable energy resources.
    - Regulations that fully account for the costs of carbon dioxide emissions.
    - Reductions in the cost of large-format Li-ion cells and systems.
- Single energy storage system providing multiple value streams: the flexibility of the DynaPeaQ system allows multiple value streams to be demonstrated.

Environmental

- Supporting integration of renewables: the DynaPeaQ battery system will smooth highly variable output from wind turbines, hence minimizing the need of regulating power and use of non-green on-line spinning reserve, i.e diesel generators. In the test cases this will only be demonstrated in small-scale. In addition, having demand response with green electricity will enhance the integration of the renewable in the community.

- Reducing CO_2 emissions: greenhouse gas production will be limited, both locally, by curtailing non-green on-line spinning reserve; and regionally, by lowering overall requirements for e.g. fossil fuel generation from the main land through the HVDC link.

Social

- Improved power quality and reliability: the dynamic voltage support of ABB’s SVC Light system provides improved power quality for local loads, while the extra dimension of fast-acting energy storage allows for prolonged support (islanding) for pre-defined loads.
- Availability of emergency power: in the event of a loss of main grid power, pre-defined loads will be fully supported for a limited time.
- Possibility for island operation of predefined feeders by using the energy storage in combination with the wind power Implementation (detailed).

5.2.3 Scope of supply

The project includes the installation of an STATCOM with the rating of +/- 6 MVAr with a battery storage connected at a 10 kV substation. The battery storage system consists of 3 battery rooms à 3 parallel battery units and 108 battery modules, hence, giving a capability of 3.6 MW for 15 minutes at the beginning of life. The design life time depends on the calendar ageing as well as the cycling ageing. Regarding the cycling ageing, batteries degrade in predictable ways when subjected to repeated charge/discharge cycles in a controlled manner. In addition, the main life-determining factor for the battery might be either the larger SOC swings or the microcycling, that is the number of complete charge-discharge cycles.

The project also includes civil works, installation, commissioning and acquiring of the land area needed. In addition the project includes development of control strategies and algorithms and development of interaction/integration with overriding SCADA system in terms of load flow (actual and prognosis) and weather forecast (short and long term). After commissioning test operation for 2 years and an additional operation period of 3 years are within the project scope. The batteries and the operational sequences are aiming at an expected lifetime of Batteries of more than 5 years (i.e. down to 80% of initial capacity).

STATCOM

As already known, a STATCOM is a power electronic converter used as a reactive power compensator. With a STATCOM, the reactive power absorbed/injected can be varied continuously. In addition, the speed of response of STATCOM is higher than traditional SVC systems, thereby being able to counteract much faster variations for e.g. voltage by varying the reactive power absorbed/injected. STATCOM utilizes a VSC connected in shunt to the grid at both distribution and sub-transmission level. The STATCOM concept of ABB is called SVC Light.

The energy storage, which can be added to SVC Light, is based on batteries, since a high amount of energy is needed and the required discharge time is in the range of minutes to hours. Figure 15 illustrates the dynamic battery storage system consisting of an SVC Light together with a number of parallel-connected battery strings on the DC-link in order to obtain high power. Each battery string consists, in its turn, of a number of series-connected batteries in order to build up the required voltage level.

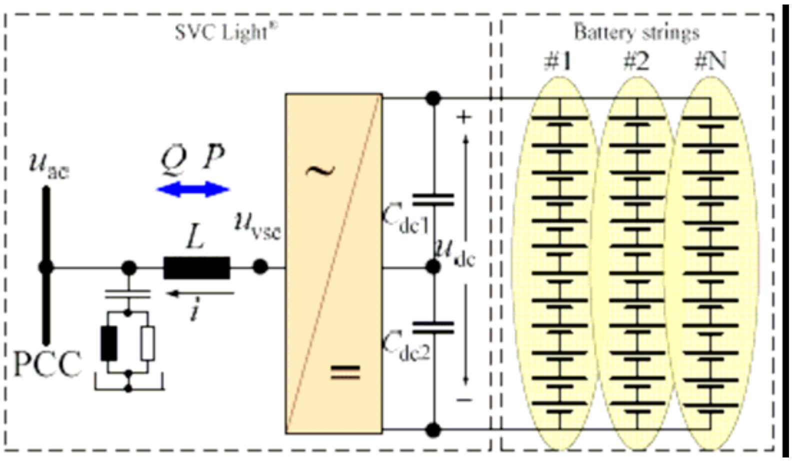

Figure 15: Schematic layout of SVC Light with Energy Storage.

Battery system configuration
In order to provide the specified active power to the system, the configuration of the battery system is as follows:

- The battery string is composed of 3 battery rooms in series. Each battery room has a nominal voltage of 3 kV.
- Each battery room is composed of 4 battery groups in series,
- Each battery group is composed of 3 battery units in parallel,
- Each battery unit is composed of 3 battery modules in series,
- Each battery module consists of 63 medium power lithium-ion cells; each with a nominal capacity of 41 Ah.

Figure 16 shows a schematic figure showing a battery room.

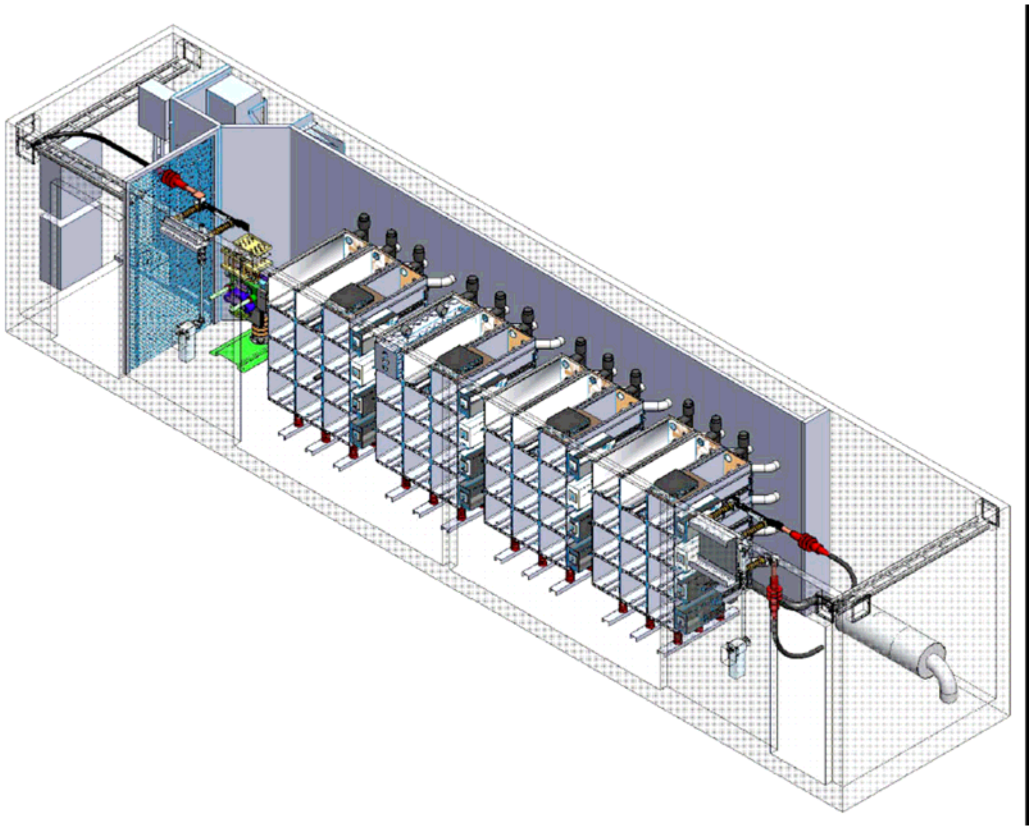

Figure 16: Schematic figure showing the fundamental idea of a battery room.

Scope of delivery

The project related to network support includes:

- Purchase of land and pre-processing of the land to a gravelled surface with specified buoyancy.
- Engineering, equipment delivery, civil works, installation and commissioning of energy storage and STATCOM including buildings (turn key).
- Development of appropriate control algorithms and functions in the Development project.
- Performing and evaluating of the described test cases.

Location

The apparatuses will be installed in Källunge 70/10 station in the middle of Gotland (close to Visby.

Connections to 3rd parties, external parties involvement

The benefits from the network support area is mainly in the network stability, and quality of supply, e.g. Islanding. To be able to make money on e.g. arbitrage the amount of energy stored and the price volatility should be much larger. External parties gaining benefits from this system are customers, e.g. power consumers and producers, e.g. wind power plant owners.

5.2.4 Dependencies to other SGG areas and functions

Smart rural grid

The energy storage will be installed in substation deployed by the smart rural grid part.

For control and measuring of the energy storage system needs current and voltage transformers for the incoming and outgoing bays controlled by energy storage system. These measurements can, if possible, be integrated in measuring transformers if separate cores are used for the energy storage. If not, the energy storage need separate measuring transformers.

To be able to reconnects to the grid after operated in island mode there needs to be a synchronized switch installed in Källunge substation. This should be integrated by the project part responsible for the substation when developing the new substation.

ICT

Energy Storage and DSO SCADA system will have a communication channel for exchange of data.

Examples of data to be transmitted is the battery state of charge from the energy storage to DSO SCADA system and wind/load forecast from the DSO SCADA system to the energy storage. The DSO SCADA system will also send orders to the energy storage control system regarding what applications should be in service during different time frames.

The communication between the DSO SCADA system and the energy storage system will be handled and coordinated by the ICT activities. The DSO SCADA system will collect information of wind and load forecast and communicates them to the energy storage system.

5.3 Demand participation (DP)

The overall objectives for the Private/SME customers and industries demand participation are mainly to find out the potential of demand response (change consumption based on price signals) and the potential of energy efficiency (reduce the consumption) and how that can affect the electrical system. This is achieved by identifying and measuring the customers' reactions and behavioural changes when they are introduced to new market models with price signals and technical tools. The findings regarding both the DP potential and market models will be an important knowledge base for future work and implementations.

The objectives for Demand participation within the research project Smart Grid Gotland are described below as well as some challenges that will be met during the project.

1. Acquire knowledge of **consumer behaviour** on a real market with stronger price signals and technical solutions for DP implemented:
   - to understand to what extent consumers are willing to participate based on current spot market prices.
   - to understand how many customers that will participate and how much they are capable of shaving and shifting their consumption – specifically if the potential for shaving is much larger than the potential for shifting
2. Acquire knowledge of how a**n improved market can be implemented** to handle large amounts of intermittent renewable power production:
   - to understand the necessary incentive needed for the intraday DP in order to get enough consumers to participate - on top of the day a head prices,
   - to understand the Impact on revenue and cost for other actors like suppliers, DSOs and potentially new aggregator roles.
   - to get a high-level understanding of the needed incentives and the level of balancing capacity available when scaling up the results from the project for other European markets.

3. Test **technical solutions in the whole system** from intermittent production to customer premises:
   - to understand if available technical solutions are sufficiently cost efficient, easy enough to use and maintain
4. Transfer experiences from the project into **commercial applications** in the coming years:
   - The project shall integrate and test technology and products available on the market to minimize future development efforts.
   - The solution developed shall easily be adapted by other smart grid networks with similar ambition related to energy efficiency.
   - Interaction with new standardization work, in this rapidly progressing area, will enable easy access for other companies and solutions to expand and further develop the results from SGG.

Some of the challenges the project will meet in order to reach the objectives:

- Find technical solutions at a cost level and ease of use that still gives the consumers enough incentives to participate on a broader scale and not only the already motivated 10-15%
- Find supporting price models and grid tariffs, and to get acceptance to test them without breaking existing legislation and discriminating customers in any direction
- Get the entire system, with components from many partners, to work and be integrated with existing solutions for Gotland
- Design a communication package to sell this to all stakeholders, consumer, public & press and authorities

5.3.1 Implementation overview

This chapter gives an overview of the system and technical components that will be used to implement DP based on new price models and tariffs for the customers and prosumers.

The technical conditions will vary between the customers segments Private&SME and Commercial&Industry. The main technical components are depicted in the picture below.

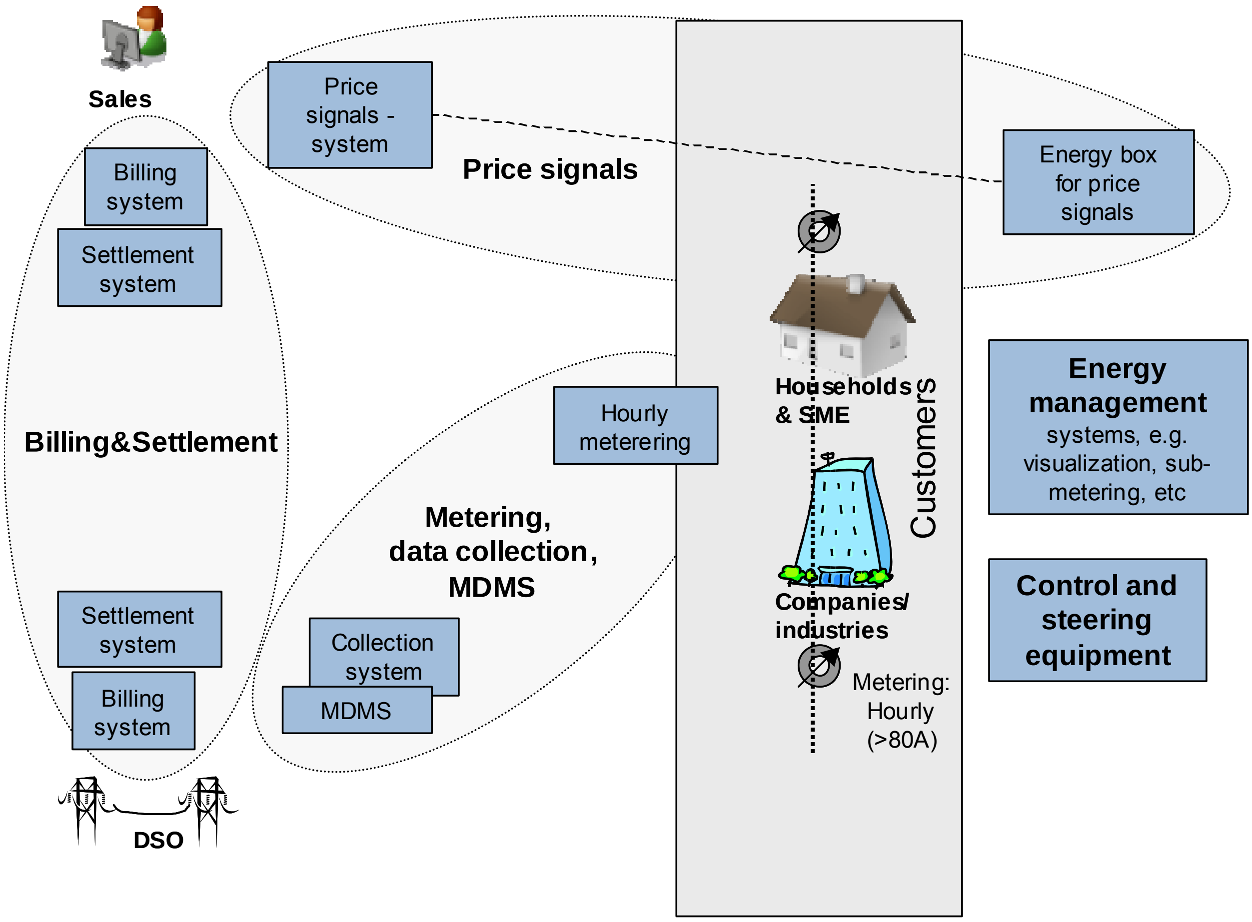

Figure 17: Main technical components related to DP.

Metering, data collection and MDMS

The customers with a subscription of 80 A or more (Commercial & Industry) already have hourly metering implemented. For customers with 63 A or less (Private & SME), monthly values are today used for billing. C&I customers may also have several subscriptions with 63A or less.

Hourly metering is a prerequisite for new price models and grid tariffs based hourly values. Therefore the whole chain from the meter, the data collection system and the meter data management systems need to be upgraded to handle hourly values.

The DSO is responsible for the metering and need to implement the changes needed for hourly metering.

A consumption baseline from some potential participants including minimum a full year before the trial is essential for analyzing the potential of DP in full after the pilot. This data should be collected before the customers are invited to get a clean baseline. Data from customers that choose not to participate will be good to keep collecting during the trial in order to have them as a large reference group. This baseline should collect hourly values to make it possible to identify peak shaving and shifting.

Billing and settlement

Both the DSO (tariffs) and Sales (prices) need to handle billing and settlement on an hourly basis. The billing and settlement systems handle already hourly values for commercial &industry customers from 80A and above. But new more dynamic tariffs and price models need to be implemented for the tests in SGG. For Private & SME customers, the billing and settlement systems do not currently handle hourly values, so the systems need to be upgraded to handle hourly values and more dynamic tariffs and prices.

The customers need to have a possibility to compare the new pilot price with the “normal” cost for both tariffs and prices during the test-period so that they can understand if they have lowered their costs during the pilot. If a customer wants to end the participation in the market pilot the customer must have the opportunity to go back to the “normal” price and tariff model.

The current prices and tariffs offered by GEAB are found in the appendix.

Price signals

There is no DP implemented today on the private customer side. Some larger industries customers with hourly prices they handle DP themselves and move the use or electricity to periods with lower price.

Customers participating in DP need to get signals in order to know when to take action in order to reduce/change their consumption. A system that is sending price signals or other signals to the customer is thus needed. This system could be handled by different actors like the DSO, supplier or an aggregator.

The customer need to have some type of energy box that can receive price signals and give the customer the possibility react on the signal, either directly or automatically.

If direct control of equipment is allowed in the customer agreement the signal might be an action to power off or lower the temperature on the customer equipment for a certain period.

There will be requirements on the customer side to provide an Internet connection.

Energy management including visualisation

The customers need to know their current and historical consumption in order to contribute to DP. If the customer should decide on action based on signals he might also need additional information about personal prognosis in both consumption and cost as well as prognosis on other parameters like production and wind. Knowing the real-time consumption, customers are given the possibility to reduce their consumption if they take action. Functionality for visualisation of consumption, comparison of consumption to other houses with similar conditions, etc can be included in an energy management package supporting the customers participating in DP. Also additional energy efficiency advice via Internet or via telephone can be included in the energy management package, as well as different types of consultancy services.

It is assumed that customers provide an Internet connection and a PC and/or or a mobile phone to be able to use these tools. There are also some tools that could work without Internet, like an in-house display.

Control and steering equipment

Effective implementation of DP requires technical solutions that can help customers to automatically react on price signals. It cannot be expected that all customers, both Private&SME and C&I, will be very active and follow price signals in order to manually take different actions to optimize their consumption and production. Manual actions are definitely also an important part, but not the only. Technical solutions for control and steering of equipment that can adjust the electricity consumption are needed in a home or in a factory. This equipment will most probably need installation by a technician.

Customer advice and services

In addition to the technical solutions there is also a need to support the customers with advice and services.

5.3.2 Technical Systems for Private & SME segments

The customer segment related to Private Customers and Small and Medium-sized Enterprises requires packaged solutions suitable for supplementing or refurbishing the current installation using non-expensive control equipment, controlling a single or few load points and not on a full smart home (since that is not part of SGG). Steering will focus on the heating component for private customers and the SME customers are mainly farmers and the potential steering will be peak shifting on some grain mills (corn mills). This steering can be achieved using wireless solutions, such as plug adapters, controlled by the energy-box.

This is a market where technical solution are developing rapidly at the moment and the tools available today might be replaced by better and less expensive tools tomorrow. In order to provide the project with the state-of-the-art products, the tools will be selected as close as possible to the start of the tests.

Proposed solutions are illustrated, and further described below:

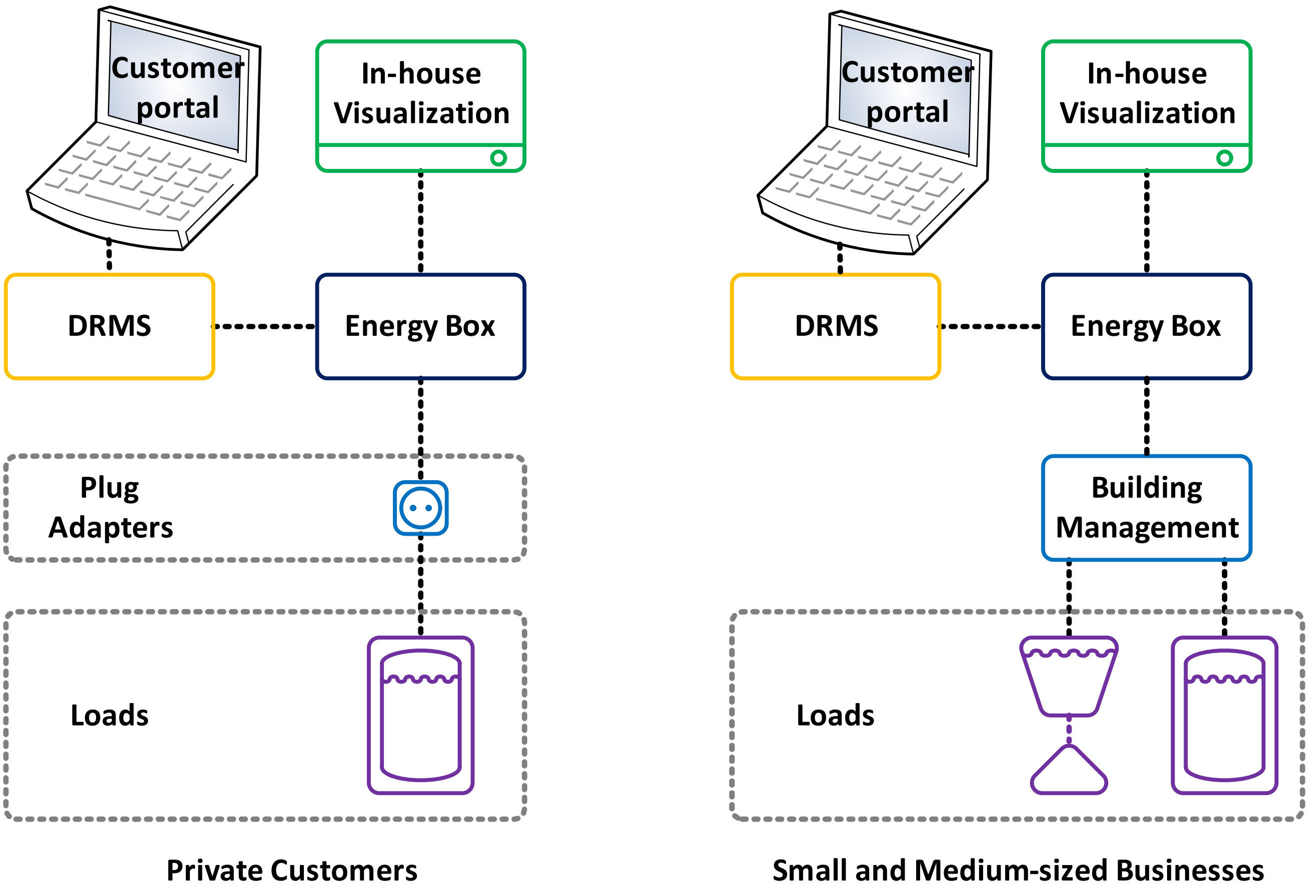

Figure 18: Technical solutions Private & SME participation.

Loads

Existing Loads, such as water boilers, heating systems, heat pumps, and farmers´ grain mills will be possible to control with minor changes, allowing for load shifting to periods with low energy costs. The solution for household loads will be based on plug adapters and wireless communication. Due to the distance between the energy-box and load connection points for SME, as well as the size of load (both voltage and current), a wired solution might be required.

Plug Adapters

The Plug Adapters are placed between the power outlet and the appliance plug. These communicate with the energy-box either directly or through a gateway depending on the type of protocol used.

Energy Box

The Energy Box provides Energy Management capabilities, using demand response signals as input and optimizes energy consumption by the controllable loads. The box also provides the user with current consumption information, based on meter integration. The meter data is also communicated to the DRMS for demand response availability calculation purposes.

DRMS

The Demand Response Management System (DRMS) is a centralized system that handles the demand participation. DRMS communicates with the energy-box using a broadband connection owned by the customer to send out price signals and more direct DP signals .

In-house visualisation

An In-house visualisation tool will be available where customers will be able to view current consumption as well as demand response information. The customer uses the tool for overriding the energy management function of the energy-box.

Customer Portal

In addition to the in-house display, customers will be able to logon to a customer portal where additional information, such as historic hourly consumption, will be available and demand response contract can be managed. This portal will also be used for informing customers of the hourly energy prices for the next coming period (based on spot market prices).

More detailed information is found in the appendix.

5.3.3 Technical systems for Commercial & Industry segments

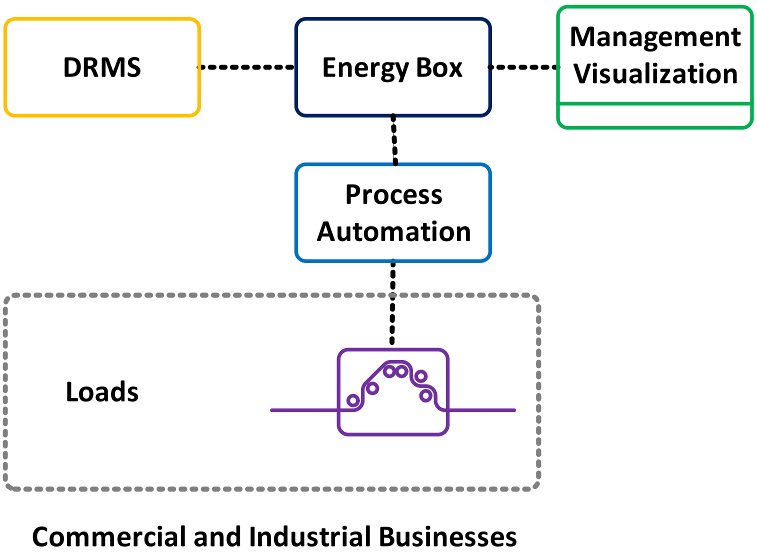

Figure 19: Commercial and industrial business system overview.

The systems and technical components for Commercial and Industrial Businesses will require more flexibility as the implementation needs to be adapted to the different processes. Different customers segments have their own existing systems as well and it is therefore difficult to develop generic packages for these customers. As basis for the proposed solution is a Process Automation System.

Loads

The Loads are typically components that are part of the process, such as electric motors used for fans and compressors etc. Some of these loads can be shifted to times when energy prices are low as well as used for load shaving during peaks.

Process Automation System

The Process Automation System improves the productivity and achieves sustainable competitive advantages through integrated information for common visualization and plant-wide collaboration. The system performs the optimization of operations based on demand response signals.

Energy Box

The Energy Box provides the Process Automation System with demand response signals such as price curves and demand response requests. An In-house Display is not required as the Process Automation System handles the optimization and operator communication.

DRMS

The Demand Response Management System (DRMS) is a centralized system that handles the demand participation. DRMS communicates with the energy-box using a broadband connection owned by the customer to send out price signals and more direct DP signals.

Energy visualisation systems

Tools like Energy Management help industries to visualize and optimize energy consumption on both operation and management levels. The tool will receive energy prices via Energy Box.

5.4 Smart Grid R&D platform

The Smart Grid R&D platform should be an environment for

- Visualization and education. Presenting results and benefits from the evolving Smart Grid, see Figure 20.
- Test and validation of new services and applications.

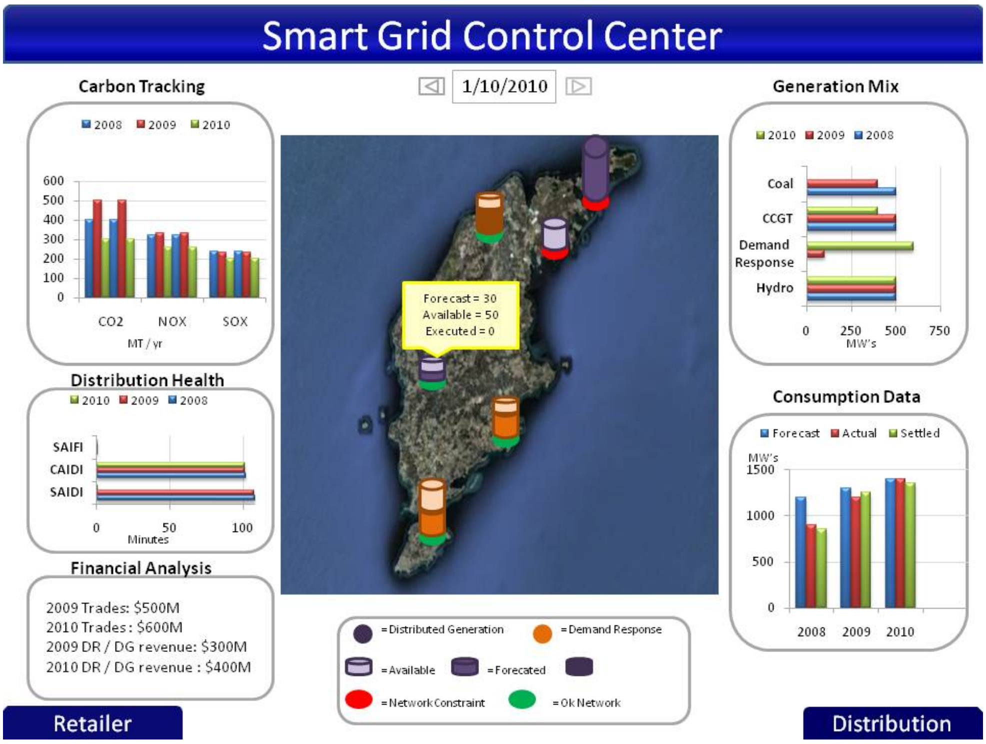

Figure 20: Smart Grid control center interface.

5.4.1 Overall architecture

It is here assumed that the Smart Grid R&D platform should be isolated from the real power system, but still mimic a real control and communication system to the largest extent possible. At the highest level of abstraction, the Smart Grid R&D platform consists of four layers, see Figure 21.

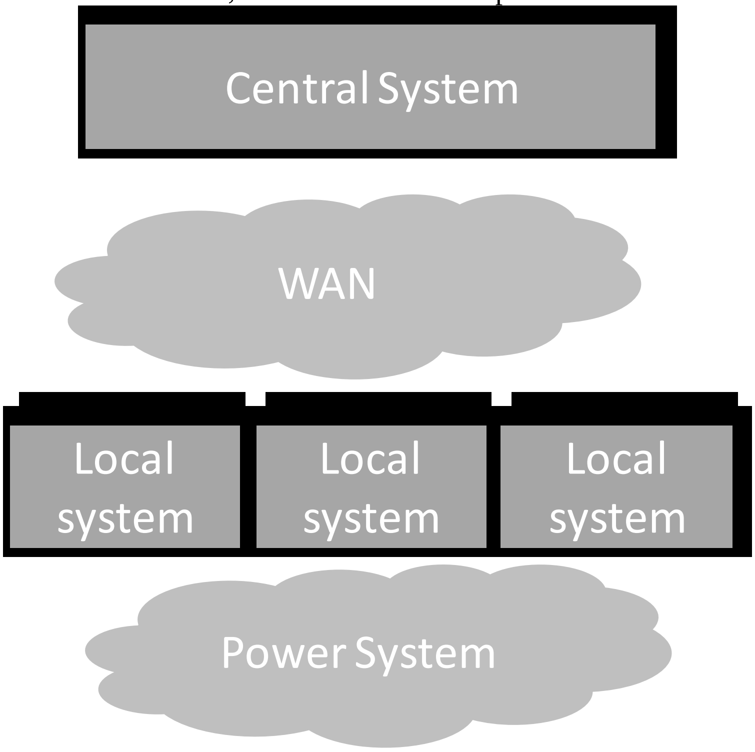

Figure 21: High level architecture of the Smart Grid R&D platform.

The top layer, the central system, is a SCADA system with associated Distribution Management System (DMS) and Energy Management System (EMS) applications, depending on configuration. The Wide Area Network (WAN) mimics a wide area communication system that connects not only the central system to the local system, but also the local systems to each other. The local systems include the typical automation and protection systems at substation and power plants. Finally, the bottom layer provides for, some form of simulated or emulated power system.

5.4.1.1 System interfaces

The interfaces between the layers in the system, i.e. the communication protocols used, should mimic those of a real communication and control system to enable interconnection to "real" system at various interfaces. In its default configuration the system would be completely isolated from the real power system and from the real communication and control equipment. However, for specific studies, there may be additional value to be gained by connecting the R&D platform to the real system, see Figure 22.

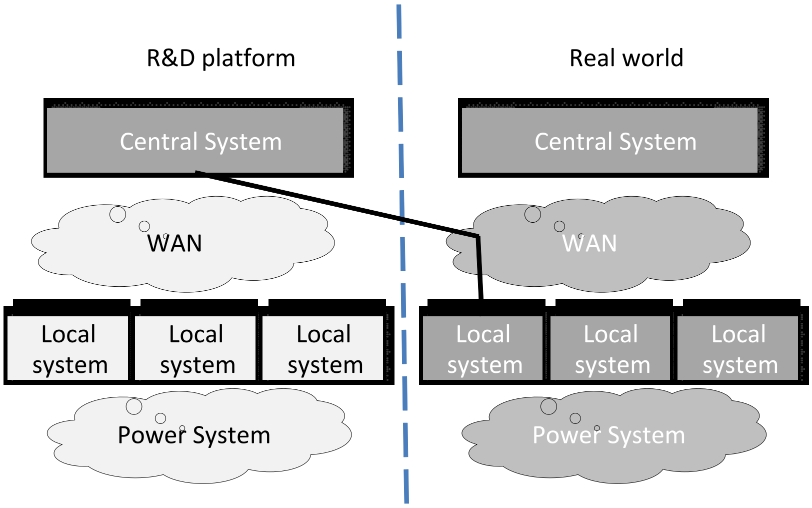

Figure 22: Interaction between R&D platform and real world system is possible thanks to use of similar interfaces (protocols) between systems and layers.

Of course such connection would be of a read-only nature, and any control actions would instead be simulated. The value of such interconnection to "the real world" is for instance to create data to be used in simulations such as load profiles. Other usage is for instance measurement of communication delays in the real-system in order to create similar environment in the R&D platform.

5.4.1.2 Distributed systems

One type of control system that is growing in importance for Smart Grid applications are distributed systems where the local systems are given more autonomy to take decisions regarding reconfiguration and other automation tasks. Since state of the art protection and automation devices, e.g. Intelligent Electronic Devices (IEDs) and Remote Terminal Units (RTUs) normally do not support such autonomy, the local system layer in the R&D platform needs to include non-standard devices such as general computing platforms (servers, industrial PCs, communication devices) to be able to implement such distributed functions, see Figure 23.

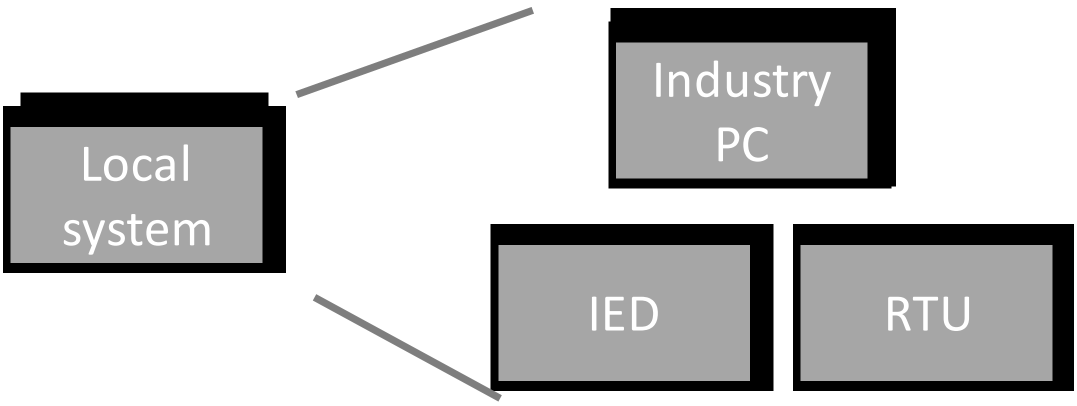

Figure 23: Expanded view of the Local systems to enable experimentation with distributed systems.

These additional platforms in the local system layer, naturally add a level of complexity, that also makes the R&D platform different from the real-world, but at the same time, this addition is necessary to be able to perform studies of more advanced system architectures.

5.4.1.3 Automatic Meter Reading systems

Automatic Meter reading is traditionally not integrated with the SCADA and control system architecture. However, such integration appears to offer many benefits for monitoring of the low voltage (LV) network, and the R&D platform should include this possibility as well.

5.4.2 Design options

This section high lights some different types of R&D studies and which type of design of the Smart Grid R&D platform and how these options provide different opportunities for studies.

5.4.2.1 Demand Response

Demand response does in itself require a specific R&D platform to be studied. The implications of demand response are best simulated since it involves a large group of users to show the interaction between the micro and macro level.
In the R&D platform, demand response solutions can be demonstrated, showing how such control signals can be sent from a central system and how the end-user devices react. The requirements for this type of studies are therefore more related to what should be demonstrated.

5.4.2.2 Self healing systems

Self-healing system, here meaning automatic fault detection, localization and restoration, requires a large degree of automation at the local layer. These types of studies include two aspects, first an algorithm aspect to develop appropriate fault localization and restoration plans. Second to develop the control systems that communicates to implement the restoration solution.

These types of studies require that the R&D platform consists of standard local system components such as IEDs (supporting e.g. IEC 61850) but also augmented with industry PCs and communication gateways to enable communication peer to peer between components for self-healing.

5.4.3 Implementation

5.4.3.1 Proposed R&D Platform solution concept

The system for the R&D platform is proposed to be located in the new control building in Visby and connected to the same Local Area Network (LAN) as the SCADA system, which is supposed to replace the existing control system. A prerequisite for the proposed solution is that the existing control system is replaced by a Ventyx/ABB SCADA system. The advantage is that the R&D system is connected in parallel with the SCADA system and to the same PCU400 front-end computers as included in the SCADA system.

With this concept we have the R&D system connected to the RTUs in "listening-mode" which gives real time data from the process and possibilities to obtain the testing environment as shown in Figure 22 in the section above.

When necessary for verification and test, an RTU can be made controllable from the R&D system. Interfaces for i.e. demand response and Advanced Metering Infrastructure (AMI) and smart meters must be defined.

From an application point of view the basic software in the R&D system is a copy of the SCADA system but with DMS and Smart Grid applications added. However, the functionality of the DMS and Smart Grid applications has to be defined.

Functionality and software modules, which are verified and approved in the R&D system, will then be implemented in the SCADA system when GEAB/Vattenfall are ready to take the new functionality into service.

The R&D system consists of the following servers

- Redundant servers for SCADA/DMS
- One historical database server Utility Data Warehouse (UDW)
- One server for Active Directory (AD)
- One Data Engineering (DE) server
- Assumed 2 operator work stations

5.4.4 Dependencies

Foreseen interfaces that have to be defined towards the R&D platform

- Network Information System (NIS)
- Demand Response
- AMI/Smart meters
- Reliable load and generation forecasts

Descriptions on applications

- Reliable load and generation forecasts as well as an optimized load and generation forecast considering controllable loads.
- Advanced DMS applications, like Loss Minimization, Outage Management, Congestion Forecast, Sensitivity Analysis that uses an extended depth of data and control.
- Demand response concept using interaction with flexible loads, local production and Spot price on power production to adapt intermittent production and increase utilization of installed capacity.
- Applications for usage of energy storage to optimize and enhance network operation.

5.4.4.1 Architecture Overview

The below simplified architecture diagram represents both systems that are part of the daily DR execution, as well as those that feed data into the DR decisions on a less frequent basis, see Figure 24.

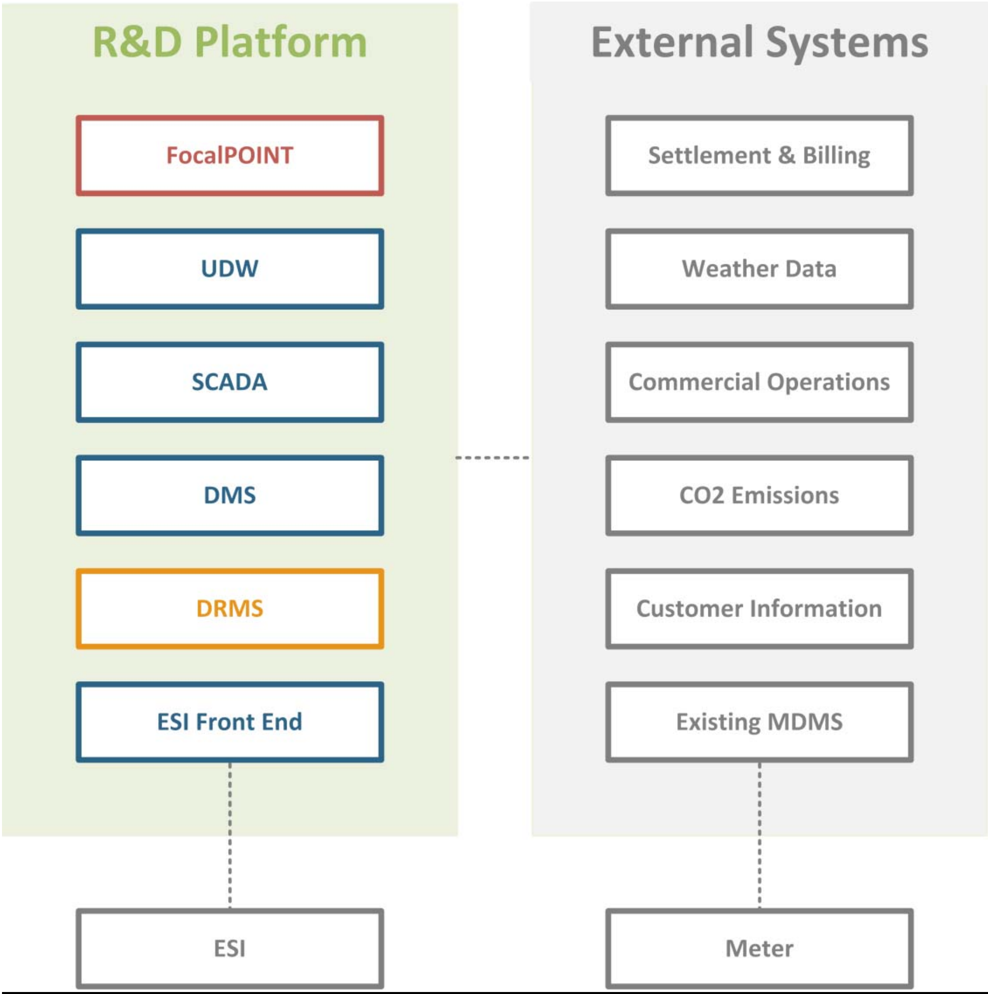

Figure 24: Architecture overview.

5.4.4.2 Roles and Responsibilities

The roles and responsibilities are outlined below for each component.

Meter

Physical meters, at household, building, and EV changing locations, responsible for providing:

- Hourly (acquired daily) and 15 minute (acquired in real-time) meter values
- Power Quality data
- Outage information
  - Last Gasp
  - Meter Status
  - Outage Confirmation

Existing MDMS

The Meter Data Management System (MDMS) handles the exchange of data with meters, and stores relevant data for analysis and settlement purposes. It will be responsible for providing validated hourly meter values to the R&D platform. One of the existing MDMS of Vattenfall/GEAB will be used for the SGG project.

ESI

The Energy Services Interface (ESI) is an energy management gateway hosting Energy Management System (EMS) logic, e.g. deciding the optimal starting time for the washing machine, and connecting the external R&D Platform Demand Response system with the home/building automation network and smart appliances. The ESI will be responsible for executing both decentralized and centralized Demand Response based on signals from R&D Platform, as well as providing feedback to DRMS. The ESI will utilize some communication equipment to the various controllable loads, i.e. appliances, EV charging poles etc.

ESI Front End

The ESI Front End is a hardware solution responsible for the communication between R&D Plattform (DRMS) and the ESI's.

Commercial Operations

Vattenfall/GEAB's different environment responsible for handling energy pricing construction (day-ahead), including energy costs, margins, taxes, V.A.T., grid tariff, as well as certificates, i.e. the total cost of energy for the end consumer.

CO_2 Emissions

CO_2 data for the generation mix of northern Europe will be sent from the Swedish TSO, Svenska Kraftnät (SvK) and can be used as an input to the DRMS module.

DRMS

The centralized Demand Response Management System (DRMS) is a solution that models and tracks demand response assets and pricing programs, supporting program design, customer enrollment, and program management. Pricing and environmental signaled programs, along with load control and distributed generation assets are aggregated into Virtual Power Plants (VPP) for forecasting demand reduction based on current weather and price conditions at multiple levels of transmission and distribution network aggregation. Post event reporting provides measurement and validation, analysis of customer override and opt-out behavior, equipment failure rates, and program economic and environmental impacts at multiple levels of aggregation from customer, feeder section, substation, and higher.

The DRMS consists of several components in order to handle the different aspects of demand response, some of them being:

- The customer contracts and ESI, forming the basis for demand response, providing availability of DR at customer premises.
- The generation optimization component, managing the Virtual Power Plants (VPPs), optimizing the use of VPPs as well as the execution of VPPs.
- The aggregator/disaggregator component, managing the DR capability accumulation from feeder section to system level, as well as allocating a DR request to feeder sections or devices at customer premises.
- The demand response calculation component, forecasting and calculating the available demand response based on customer contracts.
- The billing determinants component, handling each customer that has participated in a DR program.

The centralized Demand Response Execution process is based on DR availability, DR request, DR execution, and an analysis, as illustrated in Figure 25Figure 25 below.

Figure 25: The centralized DR execution process.

- The DR Availability Calculation is based on the measured loads acquired from the ESIs and the customer contracts. It provides the DMS with the amount of current available demand response at different levels of the distribution network for the types of DR programs available, through the use of Virtual Power Plants (VPPs).
- The advanced application of DMS will evaluate different approaches to alleviate situations that occur, both in a real-time as well as a future time perspective. The actions needed might involve DR, and the DMS will calculate the amount of DR required in order to achieve the objectives. DMS will send a DR request to DRMS. This request will contain one or several VPPs and the requested load reduction for the respective VPP.
- Based on the DR request, customer contracts etc., DRMS performs disaggregation to individual ESIs and sends out the DR signal. The signal can be of various types, dependent on the request and contracts. As the ESI manages the load reduction locally, coordinating the controllable loads, the signal to the ESI will not be on a per devise basis.

- The ESIs provide DRMS with feedback on the DR, such as opt out information and DR execution confirmation, which is aggregated and analyzed.

Settlement and Billing

Accepts billing determinant from DRMS for each customer that has participated in a DR Program

Provides billing information to each customer, based on a virtual meter where all customer meters are combined (household, EV charging, photovoltaic) and a net billing concept is used, which includes DR participation.

Customer information

Holds customer information, DR contracts, and handles the customer enrollment.

DMS

The DMS maintains the as-built and as-operated state of the distribution network, i.e. the current distribution segment/section/feeder/substation configuration.

SCADA

The Supervisory Control and Data Acquisition (SCADA) system is responsible for acquiring data from field devices, monitoring device status, as well as sending control command to these devices.

UDW

The Utility Data Warehouse (UDW) is the Ventyx solution for long term storage of data with thight integration to the Network Manager product. The UDW is responsible for storing the 15 minute meter values acquired by the ESI Front End.

FocalPOINT

FocalPoint will be responsible for displaying DR analysis results.

5.5 Information and Communication Technologies

The use of information and communication technology (ICT) is a prerequisite for the Smart Grid. The requirements on efficient, safe and reliable systems affect the implementation of ICT for the individual Smart Grid implementations as well as integration of systems within different domains. The solutions include communication media and protocols, integration of technical IT systems as well as methods and tools for IT security. The project will demonstrate state-of-the art ICT and IT security architecture for Smart Grid applications.

The work in ICT is heavily dependent on and linked to the other areas in the Smart Grid Gotland project. Likewise the work of other areas is depending on the work and results of ICT. Close collaboration with all areas is essential for a positive outcome of the project.

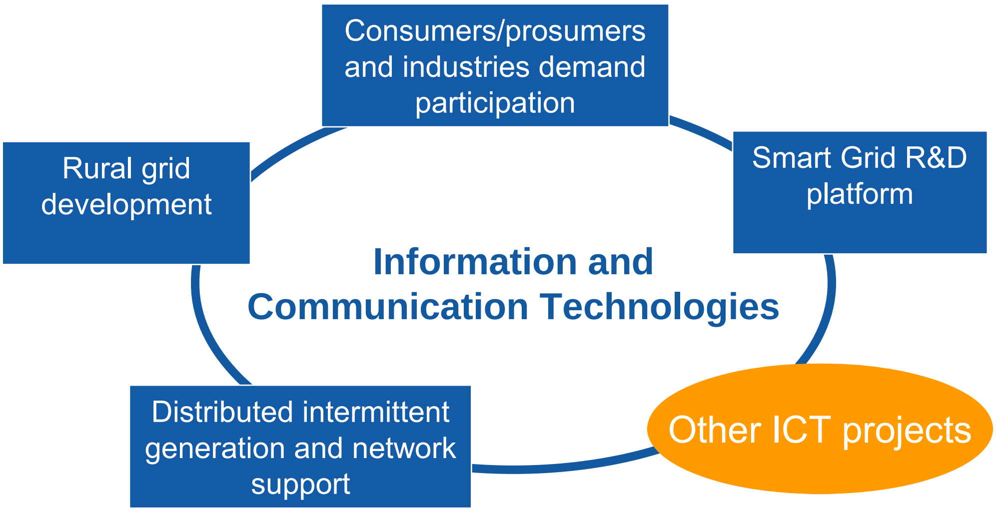

Figure 26: Interaction between ICT and the other areas defined in the pre-study.

The project identifies the requirements on the information and communication solutions for future Smart Grid implementations, including information management, systems integration and IT-security. IT and physical Security has to be taken care of in all steps such as requirements, procurement and installation, before implementation in the operations. It will be very expensive to take care of security shortages if Smart Grid solutions are already in operation.

6 POSSIBLE ACADEMIC RESEARCH PROJECTS

In the pre-study, also possible academic research projects are described. Both projects directly connected to Smart Grid Gotland as well as more general Smart Grid projects have been discussed and possible academic research projects have been presented.