Energy Markets Inspectorate

EI R2011:03

Adapting Electricity Networks to a Sustainable Energy System

– Smart metering and smart grids

This is an informal translation of report EIR2010:18 by the Swedish Energy Markets Inspectorate. Where the translated (English) version differs from the meaning of the original (Swedish) version, the original version should be used.

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Preface

If the electricity sector is to meet its climate change targets, we need to fundamentally transform both the supply and the demand sides in the electricity system. In order to carry out these transformations in a cost efficient manner, electricity networks will have to be modernized by introducing and refining a set of new technologies that go under the names *smart grids* and *smart metering*. The latter is of special interest since it will allow end-customers to participate directly in the transformation of the energy system, and also share some of the benefits of the transformation.

The Swedish Government wants to find out whether the development of smarter electricity networks can be accelerated, and has therefore asked the Energy Markets Inspectorate (EI) to investigate whether there are any significant barriers that could limit progress, and to provide further advice about possible measures designed to encourage the development of smarter electricity networks.

This investigation has been carried out in consultation with the Swedish Transmission System Operator Svenska Kraftnät and the Swedish Energy Authority. An external reference group and a public hearing have been used to gather inputs from other important stakeholders.

Eskilstuna, 30 November 2010

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Innehåll

1 Summary

Electricity networks will play a fundamental role in the transformation of the energy system

The transition to a sustainable energy system will be a huge task for society. It will mean addressing significant new challenges, including large-scale use of renewable energy sources and the electrification of the transport sector. The electricity networks will have to be developed to:

- Facilitate the further use of electricity from renewable energy sources.
- Reduce peaks in electricity demand
- Improve incentives for energy efficiency
- Create an environment where customers can be more active

Security of supply will have to be maintained, even when the amount of non-conventional generation connected to the electricity network increases. These major new challenges for the network can only to be addressed through the deployment of advanced new technologies, so-called smart grids. Smart grids will not only be required to handle new power quality issues such as overload and overvoltage, but also to improve the overall reliability of electricity networks. The adoption of smart grid solutions will allow modifying electricity networks in a flexible and efficient manner.

New Technology can be used to transform our electricity networks

The term "smart grids" describes a set of technologies, electricity market designs, and electricity market regulatory frameworks that together support, in a cost-effective manner, the large-scale use of electricity generation from renewable sources, a reduced overall electricity consumption, the reduction of peaks in electricity demand, and more active electricity consumers.

Sweden is one of the countries that has made good progress in making electricity consumers more active, and where electricity consumers have access to detailed information about their electricity use. This is a direct consequence of the metering reform and the large-scale roll out of smart meters. Sweden was one of the first countries in Europe to introduce smart meters on a large scale. Sweden is also a front-runner in the use of modern technologies, such as High Voltage Direct Current (HVDC) and FACTS, which can be used to improve transport capacity in transmission networks. These technologies will play an important role when renewable generation is introduced on a large scale in Europe.

Smart grids still face a number of barriers

Meetings with members of the external reference group, input from the public hearing, and bilateral discussions with important stakeholders, have led to the identification of five major obstacles to the successful deployment of smart grids that require further analysis:

- It is unclear who will finance smart technology R&D, demonstration projects, and the actual deployment of the smart grid
- There are currently no incentives for distributions companies to invest in smart grids
- Current network tariffs do not give consumers any incentives to reduce consumption during peaks in demand.
- There is no comprehensive national action plan for the future development of the electricity networks
- There is a general lack of knowledge about how smart grid technology works and what its benefits are

In a separate project the Energy Markets Inspectorate has investigated whether there is a need for further minimum functional requirements for smart meters, in addition to those requirements identified by investigations commissioned by the Swedish Government regarding net metering and hourly meter readings.

As a result of this project the Inspectorate has identified a number of barriers that that could hinder the deployment of smart meters in Sweden. Firstly, there is a general lack of knowledge about smart grids in the electricity companies. Second, research related to electricity networks has a low priority. Third, there are no strong incentives for distribution companies to invest in smart grid infrastructure. Fourth, there is no comprehensive national action plan for the future development of the electricity networks. Fifth, current network tariffs offer consumers no incentives for shifting demand, and lastly there is a lack of relevant information services aimed at customers.

To remove these barriers, a number of measures are required

This investigation has resulted in the following proposals:

- The establishment of a knowledge platform to track relevant knowledge and information about smart grids research, development and demonstration and distribute it to all stakeholders. An independent coordination council shall steer the knowledge platform.
- Financing of research, development, and demonstration projects shall be managed using existing mechanisms. However, the Energy Markets Inspectorate shall be given increased influence on the distribution of resources and shall be given resources to develop market design and regulatory frameworks in the electricity sector.
- Svenska Kraftnät, the Swedish TSO, shall be assigned to develop a national action plan for the development of the Swedish electricity network with a view to supporting the transition towards a sustainable energy system and meeting

renewable energy targets. An important precondition for the action plan is the establishment of a mechanism for socializing the costs for connecting wind power and other renewable energy sources.

- Incentives for investing in smart grid technology are incorporated into the tariff regulation for transmission and distribution network operators.
- Hourly metering is extended to most electricity consumers.
- The Energy Markets Inspectorate is assigned to investigate what kind of network tariffs will be required to reduce demand peaks.
- The Energy Markets Inspectorate is assigned to develop functional requirements on consumption feedback in order to give electricity consumers the information they need to respond to price signals in a meaningful way
- The Energy Markets Inspectorate is given the responsibility to investigate the roles and responsibilities of the different parties in the electricity sector in order to identify and propose measures that will accelerate the development of smart grids in Sweden
- The Energy Markets Inspectorate is assigned to investigate if the current division of the electricity grid in trunk, regional and local networks is appropriate.

Dates for when these proposals must be implemented have not yet been set, and will have to be synchronized with the regulatory periods that govern the activities of network companies. Results should be available well before March 2015 in order to give network companies sufficient time to modify their investment plans. Currently, Autumn 2013 is proposed as the target date.

2 Introduction

2.1 The assignment

The Swedish Government has asked the Energy Markets Inspectorate (EI) to examine issues related to smart metering and smart grids:

"Concerning smart meters it should be examined how their use can be extended. In particular, the project should examine to what extent the benefits from an extended deployment of smart meters can be realized, and which minimum functional requirements on smart meters would be suitable."

"Concerning smart grids it should be examined how the deployment of the smart grid can be facilitated. In particular, the project should examine how smart grids can facilitate a transition to a sustainable energy system, identify obstacles to the development of smart grids, and propose measures that lead to an increased use of smart grids in a cost efficient manner."

2.2 Premises for the assignment

The project has been carried out with an understanding that the purpose of smart grid and smart metering deployment is to:

- Facilitate the further use of electricity from renewable energy sources.
- Help reduce peaks in electricity demand
- Improve incentives for energy efficiency
- Create an environment where final customers can be more active

These premises will be described in further detail in the next chapter.

2.3 Project organization and execution

The project has been carried out in consultation with the Swedish Energy Authority and the Swedish Transmission System Operator Svenska Kraftnät. During the project, several consultation meetings have been held with these two partners.

During the project opinions have been gathered from an external reference group consisting of representatives from Swedenergy, Svenska Kraftnät, the Swedish Energy Authority, the Interactive Institute, the distribution arms of Fortum, Skellefteå Kraft, and Vattenfall, the production arm of Vattenfall, E.ON, Landys & Gyr, supplier Egen El, Lund University, Chalmers University of Technology, the Swedish Competition Authority, the Swedish National Electrical Safety Board, Aidon, and Electrolux. Additional views from stakeholders were gathered at a public hearing that was held on Aug 31st, 2010.

Project manager has been Math Bollen. In addition Peter Albertsson, Lisa Almén, Bengt Gustavsson, Rémy Kolessar, Marielle Liikanen, Marina Lindqvist, Johan

Roupe, Lars Ström, Daniel Torstensson and Thomas Westergaard participated in the project.

During the project the Energy Markets Inspectorate has purchased consulting services from SWECO and STRI AB. SWECO undertook a survey of socioeconomic cost-benefit analyses for smart grids (Appendix A: Compilation of socioeconomic cost-benefit analysis of smart metering and smart grids, only available in Swedish), and a survey of regulatory frameworks related to smart grids and smart metering in a selected set of European countries (Appendix B: Regulatory frameworks for smart grids and smart metering, only available in Swedish). STRI performed a study of developments in technologies related to the connection of installations producing electricity from renewable energy sources to the electricity networks (Appendix C: Survey on technologies and applications for more RES integration, only available in English).

2.4 The deregulation of the Swedish electricity market

The Swedish electricity market was deregulated on January 1st, 1996. The purpose of the reform was to create conditions that would lead to a more rational use of production and distribution resources, and to provide electricity consumers with flexible delivery options at the lowest possible cost. Electricity networks were separated from the activities of electricity generation and electricity supply. Electricity generation and electricity supply take place in a competitive environment, whereas electricity transportation, a natural monopoly, remains regulated. The regulation aims to ensure that the electricity networks are accessed in a non-discriminatory manner by all users, that the networks are operated as efficiently as possible, and that network companies are not able to abuse their monopoly position to boost profits.

One important aspect of network regulation is that network tariffs should be reasonable and fair. It is up to each company to set its own tariffs, but tariffs must be fair according to the Electricity Law. Sweden currently uses ex post regulation for network tariffs.

The Swedish Parliament decided on June 16th, 2009 that ex post regulation of distribution network tariffs would be replaced by ex ante (upfront) regulation. This means that during 2011 the Inspectorate will decide in advance on the total revenue that each network company is allowed with the exception of Svenska Kraftnät, for whom the Government will make the decision.

The new ex ante regulation will come into effect in 2012. The purpose of the new rules is to create a more predictable environment for electricity network companies and their customers. Under the new rules, the Inspectorate decides in advance on the level of revenue that companies will be allowed during a four-year period, after which companies submit their network tariff to the Inspectorate for approval. The Inspectorate will set the level of revenue to ensure network companies earn a fair return after capital and operating costs, taking into account the efficiency in system operation. This means for example that revenues can rise and fall based on the quality of electricity supply.

2.5 Electricity market participants

2.5.1 Generators

An electricity generator company owns one or more power plants and sells the electricity produced there to electricity suppliers, on wholesale electricity markets such as Nord Pool Spot. Electricity network companies are obliged to measure all electricity that is injected into their networks on an hourly basis. These measurements are then used by generator companies for settlement and billing purposes with the suppliers that the generator company has delivered electricity to.

2.5.2 Electricity network companies

Electricity network companies have a concession to build and operate electricity lines. A concession requires network companies to transport electricity. Network companies are not allowed to produce electricity or sell electricity. Network companies are also required to measure the electricity flowing in and out of its grid, to perform various calculations on these measurements, and to make both measurements and calculations available to consumers, balance responsible parties, and Svenska Kraftnät. These measurements and calculations are used for all physical electricity trading and it is therefore important that this information is of high quality. Network companies have metering agreements with Svenska Kraftnät that are used among others for balance settlement.

The electricity grid is the infrastructure that allows the transport of electricity from where it is generated to the where it is consumed, and is therefore a vital component of the electricity market. Capacity problems in the grid constrain the electricity market when trades cannot be completed. Network companies are monopolies because there is only one company for each concession area, which means that electricity consumers cannot select the network company that they want to be connected to. To prevent network companies from abusing their monopoly, the Inspectorate limits the amounts consumers can be charged by regulating the revenues of network companies.

Chapter 3 § 1 of the Electricity Law states that network companies are required to operate and maintain grid lines in their respective concession areas. Each network company is also required to extend its part of the grid, or to connect its grid to neighbouring grids, if this is necessary for the functioning of the electricity market. Network companies are also responsible for keeping their networks safe, reliable, and efficient. They are also responsible for ensuring that their networks will be able to transmit electricity in the longer-term.

It is thus the responsibility of network companies to upgrade their networks with a view to integrating increasing amounts of electricity generated by renewable energy sources and facilities required for the electrification of the transport sector. The formulations in the Electricity Law are technology neutral and emphasize safety, reliability, and cost efficiency.

Investments in network and metering equipment made by network companies may create benefits for other electricity market actors other than themselves, including consumers. Network company’s investments may for instance pave the way for new services. Network companies’ activities are regulated and companies are guaranteed revenues that will provide reasonable cost coverage and return on investments. Therefore, network companies' role and responsibilities differ from those of actors participating in the competitive markets.

The technological developments that are described by the terms smart grids and smart metering give network companies the opportunity to operate and plan their activities in a more efficient manner. Even though many technical details and financial aspects are still somewhat unclear, the general view is that these technologies will reduce the need for large-scale investments in electricity networks. Longer-term, this may lead to financial advantages for electricity consumers as well. A smarter grid is needed to profit from technologies such as demand management and energy storage, also of interest to participants outside the regulated energy market.

2.5.3 Consumers

Electricity consumers are households, companies, or public entities. An electricity consumer has a business relationship with an electricity supplier that sells electricity, and with a network company that provides access to the grid. The various forms that these relationships can take are discussed in section 2.4.

2.5.4 Suppliers

Electricity suppliers sell electricity to consumers and act in a competitive environment. The price for the electricity delivered is specified in a contract between supplier and consumer. A supplier that acts as a balance responsible party can sometimes be denoted as an electricity trading company. Under the Electricity Law, an electricity supplier can be both a party that delivers electricity and a party that assumes balancing responsibility.

2.5.5 Balance responsible parties

An electricity supplier is obliged by law to make sure that all electricity that is consumed by its customers is delivered. In order to do this, the supplier must turn to a party that assumes balancing responsibility, i.e. taking the responsibility that supply and consumption match. There must be a balance responsible party for every point in the grid where electricity is consumed. A supplier can either assume the balance responsibility for a consumer itself, or it can buy the service from another company that assumes balance responsibility for the consumer. A balance responsible party enters into a balancing agreement with Svenska Kraftnät and is required to ensure that for every hour, there is supply that matches the withdrawal of electricity of all consumers for which it has assumed balance responsibility. Svenska Kraftnät will check that balance responsible parties live up to their obligations during the settlement phase that occurs after the delivery hour. If discrepancies are detected, balance responsible parties have to pay Svenska Kraftnät for costs it has incurred to counter the imbalances. The balance responsibility agreement specifies the financial penalties for imbalances as well as requirements on the exchange of information between Svenska Kraftnät and the balance responsible parties.

2.5.6 Svenska Kraftnät

Svenska Kraftnät is responsible for ensuring that the electricity system as a whole is in balance at all times given the available generation resources. If Svenska

Kraftnät detects imbalances resulting from actual consumption not matching planned production, it corrects the imbalance by buying or selling electricity during the hour of delivery itself. The costs incurred are then passed on to the balance responsible parties whose supply and consumption did not match. Svenska Kraftnät is also responsible for administering and running the high voltage transmission grid and interconnectors to neighbouring countries. Finally, Svenska Kraftnät is responsible for promoting a competitive electricity market by ensuring that all networks, including regional and local networks, are open to all electricity suppliers.

3 Smart grids

3.1 What are smart grids?

Currently there is no clear and broadly accepted meaning of the term smart grid, and different actors use the term in different ways. However, two different types of definitions can be encountered.

The first type focuses on the technologies that are included in the terms. The definition used by the IEC[1] fits this category: *"Smart Grid, intelligent grid, active grid: Electric power network that utilizes two-way communication and control technologies, distributed computing and associated sensors, including equipment installed on the premises of network user."* There are different opinions about which technologies that are relevant for the terms but the following keywords often turn up in discussions about smart grids[2]:

- More measurements, communication, and more control at all levels of the grid, including distribution level
- Power electronics technologies such as FACTS[3] and HVDC[4]
- Energy storage, both large- and small-scale.
- Advanced systems for network automation and protection
- Control of small-scale generation units, both individually and in groups, and control of large-scale wind power and solar plants.
- The possibility to use demand side flexibility and small generation as capacity reserve
- Direct participation in the electricity market of more actors, including small consumers, and the development of markets for ancillary services.

The second type of definitions focuses on the problems that have to be solved. The definition used by ERGEG[5] falls into this category: "*Smart Grid is an electricity network that can cost-efficiently integrate the behaviour and actions of all users connected to it - generators, consumers and those that do both - in order to ensure economically efficient, sustainable power systems with low losses and high levels of quality and security of supply and safety*". The four goals used as a starting point in our report can also be

[1] International Electrotechnical Commission, http://www.iec.ch

[2] For an overview of technologies included in a smart grid, see "IEC smart grids standardization roadmap", June 2010, http://www.iec.ch/zone/smartgrid/pdf/sg3_roadmap.pdf

[3] Flexible Alternating Current Transmission Systems: a way to control power flows in a meshed network with the help of power electronics in only a few sections of the network. Usually, the goal is to increase transmission capacity in the transmission grid. Not everyone agrees as to what should or should not be included under FACTS. This discussion is outside the scope of this project. A small number of companies have the technology to build FACTS installations. ABB in Västerås is one of them.

[4] High Voltage Direct Current, uses direct current for the bulk transmission of electrical power, in contrast with the more common alternating current systems. HVDC is used to connect two large networks (like between Sweden and Denmark) or to transmit large amounts of power over long distances (like between Sweden and Finland). New generation HVDC (VSC-HVDC, HVDC Light, or HVDC Plus) uses more modern components that allow more control. The Sydvästlänk (southwest link) is going to be one of the first three-terminal VSC-HVDC installations in the world. ABB is world leader in HVDC technology.

[5] European Regulatory Group for Electricity and Gas, http://www.energy-regulators.eu

seen as a definition of smart grids that fits into the same category: *"to facilitate the large-scale use of renewable electricity, to smooth demand, to create incentives for energy efficiency, and to create conditions for consumers to become more active"*. In this report, we focus on those aspects of smart grids that can be used to reach these four goals. In section 6.6 we provide a definition of the term smart grids that is based on these goals.

Irrespective of how one chooses to define the term smart grids, one can safely state that electricity networks will face new challenges in the future, and that current and future challenges can be solved by a set of technologies that either exist today, or are being actively developed. The electricity networks of the future will use new existing technologies in a manner that is both cost and technology effective to solve the problems faced by the electricity networks. It is the actual transition from the electricity networks of today to the electricity networks of the future that we think of when we use the term smart grid.

In this report we will use the terms electricity network in a manner that is somewhat different from the way the terms are commonly used in power engineering and in regulation. We will use the terms to describe any component that either facilitates or hinders the transport of electricity from generator to consumer. The following aspects are included in our definition of the term:

- Transmission grids, regional and distribution networks, and grid lines inside industrial facilities or buildings
- All types of communications and control equipment required to operate electricity networks
- System services and relevant market services
- The interaction between generation and consumption.

The actual generation and consumption of electricity is not considered to be part of the electricity network, but control of generation and consumption in order to facilitate the transport of electricity are considered to be part of the electricity network.

3.2 Smart metering

There is currently no generally accepted definition of the term smart metering. Descriptions of the term generally contain both a description of the functionality of the equipment, and a description of the services that the technology supports. In this report, we focus on the former - the functionality of the equipment. There is ongoing work, especially within the EU, to define minimum functional requirements for meters, and to define the capabilities that a meter must have if it is to be called a smart meter. Two key properties of meters are often mentioned in discussions about smart metering:

- Interval metering - usually on an hourly basis or shorter. There are even discussions about real-time metering.
- Two-way communication between the customer site and the network company, or between the customer site and the electricity supplier.

Interval metering provides enhanced metering capabilities set to open up a range of new services to customers, including more advanced electricity and network tariffs and detailed feedback that might lead to increased energy efficiency. It will also allow consumers to take part in various ancillary services.

Two-way communication is not really part of the measurement functionality of meters, but it is a function that is provided by most meter manufacturers. Two-way communication allows suppliers and network companies to push information about price changes to consumers in real time. It also gives suppliers, network companies or other actors the opportunity to control consumption and production when the need arises.

Many actors see smart meters as a precondition for smart grids. Others, ERGEG included, believe that it is possible to create intelligent electricity networks without smart meters[6].

It is worth pointing out that the services made possible by smart metering require not only advanced functionality in the meters themselves, but also an infrastructure for communication, data gathering, and data processing. Market designs and processes for balancing and settlement must also be modified in order to benefit from the meters' advanced functionality. Applications that require a shift in consumer behaviour will also need mechanisms to provide information to consumers in an appropriate manner.

It is also worth pointing out that the benefits of smart metering go beyond those related to how electricity markets work. For instance, hourly meter readings for the majority of consumers would give network companies access to valuable information that can be used to optimize network operation and network planning.

3.3 Facilitate the integration of electricity from renewable energy sources

Large-scale use of renewable energy sources for the production of electricity will bring major challenges for the electricity network[7]. Sweden is looking at an increased number of smaller wind farms being connected to local networks and large wind farms being connected to regional networks or even the transmission grid. Electricity generation from solar power is still negligible in Sweden but may become more important in the future.[8] The share of biofuel-fired combined heat and power (CHP) plants is also expected to increase[9]. In the remainder of this report we will mainly be concerned with wind power, even though the effects of other renewable energy sources on electricity networks are probably comparable in nature.

[6] Position Paper on Smart Grids - An ERGEG Conclusions Paper Ref: E10-EQS-38-05 10 June 2010

[7] Hydropower if also a renewable energy source but the Swedish electricity network is already adapted to a situation with large amounts of hydropower in the north of the country and the bulk of demand in the south.

[8] Some distribution network companies have already expressed concern about the possible negative consequences of increasing amounts of solar power in their networks.

[9] Most biofuel replaces fossil fuels in existing plants and does not affect the electricity grid.

Small amounts of wind power have negligible effects on electricity networks, but when electricity generation from wind power exceeds a certain threshold level, investments in the power system will be required. This threshold level is known as the hosting capacity[10]. The level varies from a few per cent of total consumption to more than 50 % of total consumption depending on where in the grid a wind power plant is connected. A network's hosting capacity also depends on which phenomenon (such as overvoltage or overcurrent) that gives rise to the restriction.

The principle underlying hosting capacity is explained in the figure below. Hosting capacity does not say anything about how much generation from renewable energy sources that is connected to the grid, only how much can be connected without having to invest in measures to strengthen the grid. By using new technologies, such as those listed in section 3.1, it becomes possible to achieve higher hosting capacities than with investments in conventional technology. Put differently, the new technology makes it possible to achieve a given hosting capacity at a lower cost.

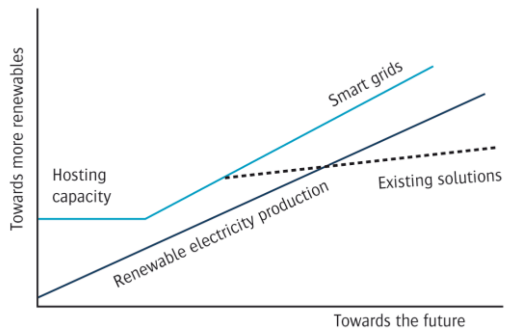

Figure 3-1: The principle underlying hosting capacity

The connection of wind farms will affect all aspects of electricity networks. While some of these effects are not specific to wind power, there are certain phenomena and consequences that are unique to wind power. The amount of wind power is expected to rise rapidly in the immediate future *(Sweden's national planning target for electricity production from wind power is 30 TWh by 2020, of which 10 TWh are to be offshore; further, in July 2009[11], Parliament set a new goal of 25 TWh generation from renewable energy sources by 2020)* and this will pose challenges for maintaining a reliable and efficient electricity grid. In the next few sections we will discuss some of the problems that will arise as a result of the connection of large amounts of new wind power. It is worth pointing out that the consequences will not be quantified in this report as hosting capacity depends to a large extent on local conditions[12].

[10] The term hosting capacity was first introduced in: M.H.J. Bollen, M Häger, Power quality: interactions between distributed energy resources, the grid and other customers, Electric Power Quality and Utilisation Magazine, Vol 1, No 1, 2005. See also EU-DEEP project, http://www.eu- deep.com

[11] Proposition. 2008/09:163 "En sammanhållen klimat- och energipolitik"

[12] For a more detailed description of the consequences of connecting wind power and distributed generation to the grid see: Math Bollen, Fainan Hassan, "Integration of distributed generation in the power system", Wiley - IEEE Press, in print and Yongtao Yang, "Power quality and reliability in distribution networks with increased levels of distributed generation", Elforsk report 08:39 http://www.vindenergi.org/Vindforskrapporter/v_150.pdf

3.3.1 Integrating electricity generation from renewable energy sources in distribution networks

When considering the effects of wind power on electricity grids, it is advisable to distinguish between effects on distribution networks and effects on the transmission grid[13].

In distribution networks, it is the actual act of connecting wind farms to the grid that is a novelty for most Swedish distribution companies. Nearly all generation units are currently connected either directly to the transmission grid or to regional networks. Many local distribution networks are not built to accommodate locally connected installations; however this does not mean that the first plants that are connected will create problems. There is a certain threshold, varying from network to network, beyond which local connections may cause problems. The first problems that will require investments in local grids are:

- Increased voltage levels due to the injection of active power during periods when consumption levels are low can lead to unacceptable overvoltages. This can occur even when only a few wind farms are connected to the network, as voltage levels are already today occasionally reaching their highest permissible values. This phenomenon is especially likely to occur in rural area networks. Adding more transformers, lines, and cables to the network usually solves these problems.
- The grid can become overloaded when local generation exceeds the sum of the lowest and the highest local demand. This situation is most likely to arise in areas with large amounts of wind power, or rural areas with weak grids, lots of wind power, and few local consumers. Again, the standard solution is to add more transformers, lines, and cables to the grid.
- When wind farms are directly connected to local distribution grids, more consumers than necessary might get disconnected due to a fault. Consumers thus face the possibility of reduced reliability. Dangerous situations in which local generation operates in unplanned island mode with local load can arise. Standard solutions include changing relay protection, installing island protection, and adding more transformers, lines, and cables to the grid.

These negatives effects that arise when wind farms are connected to distribution networks are also valid when large numbers of microgenerators are connected to low voltage networks and with biofuel-fired CHP plants.

There are a number of new methods for increasing hosting capacity without adding more transformers, lines, or cables. New advanced methods for voltage control that keep voltages within accepted limits are being developed. These methods are based on power electronics technology that is already available in many modern wind turbines, but the technology is currently not used for voltage control. There are also new methods for grid protection that can handle much larger volumes of local generation than existing methods. Both of these methods rely on measurements being taken in different parts of the grid, and

[13] There is no clear-cut division between distribution and transmission networks. Distribution networks are the local networks and the low-voltage sections of the regional networks, while the transmission grid includes higher-voltage regional networks and the trunk network. See e.g. B. Stenborg, ”Elkraftsystem Del 1”, Gothemburg, 1997.

communication between devices located in different parts of the grid. The communications infrastructure is also required to control local loads as well as local generation.

Overvoltage and overloads occur when low demand coincides with high generation, i.e. when there is a local surplus of electricity. This means that if it is possible to reduce generation and/or increase demand, the problem disappears. Reducing local wind farm generation is the simplest way to achieve local balance, but this lost generation would then have to be replaced by something else, most probably fossil-fired generation. If it were possible to consume electricity mostly during periods with a local surplus, it would be possible to increase the share of wind power. For example, the use of washing machines or the charging of electric vehicles, that do not necessarily have to take place at fixed times could be moved to times with local surplus of electricity. An alternative to controlling generation and/or demand is to use energy storage. Energy storage facilities could be placed close to where demand is, or at other appropriate locations in the grid.

The hosting capacity of local distribution networks in Sweden varies greatly. The same is true of the phenomena that restrict hosting capacity. There are variations across the country, but also within grids controlled by individual network companies. This is due to the different characteristics of rural and urban area networks, and other factors such as the distance to the closest network station and the distance to the closest connection point to the regional network. Different types of locations, with different characteristics, are likely to require different solutions. It is not possible to apply the same solution everywhere.

3.3.2 Integrating electricity generation from renewable energy sources in transmission grids

The transmission grid will be affected with increasing amounts of wind power, either as large wind farms are connected directly to the transmission grid or by local distribution networks with a high penetration of small-scale wind farms[14]. Next to that also the system (network plus production) will be affected.

One of the most important new challenges for network companies will be the additional power flows that will result from increasing amounts of electricity generation from renewable energy sources. However, this problem is not specific to wind power or other renewable generation, and is a problem that arises whenever new production capacity is connected to the grid. There are also additional power flows when new hydro plants are connected, when the capacity of nuclear power plants is increased, or when new interconnections to neighbouring grids are established. There are, however, challenges that are specific to wind power. For instance, wind power’s expansion is expected to happen relatively rapidly and in an unpredictable way. Setting up a wind farm usually takes little time compared to building a traditional power plant, and it also takes much less time than building or reinforcing the necessary grid infrastructure. Another problem is that wind farms produce power intermittently and in no way correlated to consumption. Historically, generation from existing plants has been strongly correlated with consumption: as consumption rises and falls, production

[14] See "Impact of increased amounts of renewable energy on the Nordic power system operation", ENTSO-E, August 31st, 2010, for more details on the effects of wind power on the electricity system.

rises and falls with it. This is not the case for wind power. In electricity markets with only conventional plants there are only two extreme scenarios. Either consumption and production are both high, or they are both low. In a market with large amounts of wind power, there are two additional extreme scenarios: high consumption and low production, and low consumption and high production. A further challenge with wind power is that wind farms will be spread throughout the country; wind generation could be high in one part of the country, but very low in another part. The number of potential scenarios for power flows in grids is therefore going to rise as more and more wind power is added. Since network companies are obliged to handle all potential situations, it is clear that the increased use of wind power will pose challenges for maintaining a reliable and efficient electricity grid. A further challenge concerns optimising operations with a view to network losses.

The integration of increasing amounts of wind farms is also complicated by the fact that wind power often counts as non-curtailable. Conventional power plants can be disconnected to avoid grid overload and alternative plants can come online. Svenska Kraftnät uses a method called counter-trading to financially compensate generators that get disconnected and generators that are called to provide the missing power[15]. However, no corresponding mechanism exists at regional network level, where most wind power plants will be connected.

In Sweden, there are ongoing discussions about where in the country the majority of wind power plants should be built. Several alternatives, all with their own advantages and disadvantages are being discussed. However, at the end of the day it is investors that will decide where to establish new plant by choosing the location with the highest rate of return. Therefore, electricity networks should be prepared to cope with all likely scenarios. If most wind power ends up in the southern parts of the country, it will become easier to operate the transmission grid as increased generation in the south means that the need to transport power from the hydro plants in the north to the consumption centres in the south is reduced. This leads to reduced network losses and a more stable transmission grid. On the other hand, if most wind power ends up in the north, the power from these new plants must then be transported to the consumption centres in the south over the same transmission grid lines that are used to transport power from the northern hydro plants. One way to deal with this potential congestion is to reduce the output from hydro plants as production from wind power increases so that the total flow of electricity from north to south remains more or less constant.

While reducing production from conventional power plants is one solution to handle congestion from north to south, it is also possible to shift demand so that it occurs mostly during periods of high wind power output. Large-scale storage is another solution. Excess wind power capacity generated at off-peak times could be stored and then used during peak demand periods. In many places, pumped storage hydroelectricity is used to even out the daily generation load, by pumping water to a high storage reservoir using excess capacity during off-peak hours. Pumped storage could be used in Sweden to simplify the operation of the

[15] Counter-trading is being abandoned. On November 1st 2011 Svenska Kraftnät will subdivide the Swedish electricity market into four bidding areas. This means that the market will handle grid congestions through price signals.

transmission grid if most wind power plants end up in the north of the country. However, even though pumped storage is an excellent and cost-efficient solution, it cannot be used in many locations due to environmental concerns.

3.3.3 Reduced need for large-scale power plants

Large increases in electricity generation from renewable sources will reduce the need for conventional large-scale power plants, such as hydroelectric and nuclear power plants in Sweden, and coal, natural-gas, or oil-fired power plants in many other countries. However, as the proportion of generation from renewable sources increases they may come to present a problem for the grid operator as these sources will produce power intermittently. This is especially true of wind and solar power as biofuel-fired CHP plants have low variability, are more predictable, and can to a large degree be adjusted to consumption patterns. The variations that do occur are mostly seasonal in nature.

An important consequence of large amounts of electricity generation from renewable sources and one that poses increasing risks to security of supply is that the degree to which the most expensive conventional power plants (those with the highest marginal cost per kWh) are used may drop to such low levels that it becomes unprofitable to keep them. If this reserve capacity is lost, it may become more difficult to ensure security of supply, as there will be fewer resources to meet demand spikes when there is little wind (or sunlight). Even if none of the price-setting conventional power plants are closed, it may still be unprofitable to build the additional spare capacity to support security of supply that will be needed if overall electricity demand increases. In Sweden, capacity problems usually arise as a consequence of congestion at the interconnectors with neighbouring countries. So one way to reduce the risk for capacity problems in the future is to build new interconnections or strengthen the existing ones. This would most likely entail constructing new HVDC-links to the grids of neighbouring countries. Reducing overall consumption levels can also reduce the risk for capacity shortages. Doing this might require new market models, and these new market models might in turn require that consumption for most consumers is measured and reported much more frequently (for instance hourly) than today.

Another consequence of the reduced need for large-scale conventional power plants is that there may arise situations in which there are not a sufficient number of these power plants around to operate the grid in a secure manner. These situations can for instance arise when there is low demand and high production from renewable electricity plants. Large-scale power plants are not only required to produce electricity, they are also needed to provide stable operation of the system, and provide backup power if important components of the power system were to fail. These so-called ancillary services are usually not provided for by renewable electricity plants.

When there are local or national surpluses of electricity from renewable sources, these surpluses cannot be used for ancillary services or as a capacity reserve. When these surpluses occur, the first remedy that will probably be taken is to disconnect some of the surplus from the grid. To do this for small-scale installations such as CHP plants, small-scale wind power plants connected to local distribution networks, or microgeneration will require an advanced communications infrastructure. Furthermore, if these surpluses occur very often, the total amount of electricity generation from renewable energy sources will be much less than what is theoretically possible. A possible solution might be to let both demand and renewable generation provide ancillary services and reserve capacity.

A longer-term solution is to radically strengthen interconnections with neighbouring countries. Very ambitious investment goals on renewable electricity production have been formulated at the political level, and if these goals were met, in the longer term there would be a surplus of electricity in the Nordic region. Since electricity prices in the Nordic region are expected to remain cheaper than in other northern European countries, the surplus electricity in the Nordic region would be very competitive against electricity produced in traditional coal and oil-fired plants in central Europe.

3.3.4 Difficulties in forecasting output from renewable generation

The high variability in output from wind power plants and solar plants is a well-known phenomenon and is usually described as a disadvantage of renewable electricity production. However, this is an over-simplification of the problem and it is important that wind's variability be put into context. In local distribution networks, the effects of this variability are restricted to voltage quality problems in isolated cases. At higher voltage levels, it is uncertainty over production levels that can affect the operation of the grid. At system level the problems are related to the aforementioned risks that conventional plants needed to provide reserve capacity may gradually become unprofitable and not be built or replaced. It is thus not the variability in itself which is a problem, but the difficulty in making accurate forecasts for time periods of a few hours.

When electricity generation from renewable energy sources only accounts for a small proportion of overall generation, the resulting uncertainty over production levels is no worse than the uncertainty in demand levels. The Swedish electricity system has reserve capacity of about 250 MW to handle demand forecast errors[16], and this reserve capacity can also be used to handle the effects of forecast errors for small amounts of renewable electricity generation.

As the proportion of generation from renewable sources increases, the total potential production forecast error increases, and the need for reserve capacity rises. The need for reserve capacity will be highest at times when there is a lot of generation from intermittent sources.

The Swedish power system has a very high proportion of hydropower (one of the highest in the world), which can be used advantageously to offset intermittency, as adjusting output from hydro plants is uncomplicated and cheap. A large proportion of the forecast errors that might arise as a consequence of large-scale use of wind power can be handled by controlling the output from hydro plants. However, this requires enough transmission capacity between hydro plants and the intermittent sources, and a balancing market that gives owners of hydro plants the incentives they need to deliver the required regulating power. If the interconnections with Denmark and Germany are strengthened Swedish

[16] Out of 600 MW for the whole Nordic region; Nordic Grid Code 2007. More on this in chapter 4.

hydropower could be used to handle forecast errors from wind power generation in continental Europe. Please note that this requires the reinforcement of the Swedish transmission grid the interconnectors to neighbouring countries, and the transmission grid in the neighbouring countries.

If the current supply of regulating power should prove insufficient to offset forecast errors in Sweden, emerging technologies like demand side response could play a role in balancing supply and demand.

3.3.5 The need for flexibility and smart grids

If electricity networks must be adapted to bring new renewable generation onto the grid, electricity network companies are faced with a choice between conventional measures and new, smart grid technologies. Conventional measures, such as the construction of transformers, lines, and cables, usually take a very long time to complete. It is normal for several years to pass from the moment the need for an investment is identified, to the time the project has been completed. Projects to strengthen the transmission grid can easily last ten years, whereas projects to strengthen regional networks can last five years. The construction of conventional power plants, such as hydro plants and nuclear plants, have completion times that are similar to those of the conventional network reinforcements. At the same time, demand patterns can vary more rapidly.

Integrating wind power into the transmission and regional networks is also going to be a challenge. Network companies have to consider every application to connect wind power plants to the grid and decide if the grid must be reinforced if the application is accepted. It is very likely that network reinforcements will be required to accommodate the 30 TWh wind power Sweden plans to incorporate into the system by the year 2020. But since it is still unclear exactly where most of the wind power plants will be built, it is not yet clear exactly where reinforcements will be required.

Conventional measures of grid reinforcement are not suitable for such uncertain situations. Some of the smart grid technologies on the other hand, have the flexibility required and can incorporate new technologies like demand side response and electricity storage that can be used to balance an increasingly short-term intermittent and long-term uncertain generating mix. Using the right smart-grid technology, new generators can be connected to the grid when their local connection is ready without waiting for wider system reinforcements to take place.

3.4 Reducing peak network load

The maximum load that network components like overhead cables and transformers, but even generating plants are expected to meet, determines their capacity requirements. If technology to smooth peaks in network load is deployed, the need to invest in transformers, overhead lines, cables and generators is therefore correspondingly reduced. Please note that the term "peak load" not only refers to peaks in total demand, but also high load currents between different parts of the grid.

3.4.1 What are load peaks?

In order to understand how new technology can reduce load peaks it is important to first understand what determines the need for transport capacity. A grid component, such as an overhead line or a transformer, can only transport a certain amount of electric energy. The amount of electricity that can be transported is constrained by the maximum operating temperature (e.g. 90° C) that the component can handle. A component's operating temperature is determined by factors such as the size of the current, the ambient temperature, and to a lesser extent the waveform of the current. The purpose of the component is to transfer electrical energy, and the more energy that is transmitted the better the component fulfils its purpose. One way to boost transport capacity is to replace existing components with newer, better components, but there are also several ways to achieve the same result by boosting the transport capacity of existing components. Some examples:

- Reducing current waveform distortion by installing filters that compensate for distortion caused by equipment installed at consumer premises. In most cases, this distortion is negligible, and it is only at the connection points of large industrial consumers that such filters are beneficial to increase transport capacity. In most cases, such filters are installed because network companies have requirements that distortion must be kept within certain limits.
- Reducing reactive power. Reactive power causes currents to be higher than required to transport the electrical energy (i.e. active power)[17]. Adding sources of reactive power to the grid, like capacitor banks, can compensate for reactive power. Industrial plants are often required by grid operators to reduce reactive power. Reactive power compensation is also used in the transmission grid and to some extent in regional networks. The use of the technology in local distribution networks could reduce the need for strengthening these grids with new lines, cables, and transformers.
- Smoothing demand over time so that the electricity grid is used as efficiently as possible. Demand varies greatly over time, and variations in local distribution networks are greater since variations at higher voltage levels arising from a large number of consumers tend to cancel each other out to some extent. According to statistics from Svenska Kraftnät, average hourly consumption in 2009 was 15 185 MWh while consumption during the highest consumption hour of that year was 60 % higher than the average at 24 470 MWh. If demand could somehow be spread more evenly over time the need to build new transmission lines could be significantly reduced. It is this "time shifting" of demand that has received considerable attention and is commonly seen as a key component of the smart grid of the future. There are two different approaches to manage demand. In the first, focus is placed on reducing the size of the peaks. In the second, demand is more evenly spread out over time. In an electric grid with a high proportion of renewables in the generating mix, load reductions can either be achieved by reducing demand or by reducing production. A number of methods are available: consumption and production controlled by grid operators, price signals – lower prices at off-peak times, or energy storage capacity can be used to meet demand on the grid when

[17] There is no simple explanation as to what reactive power really is, and it is outside the scope of this report. For a more technical explanation, "Kort genomgång av effektberäkningar för lågenergilampor och andra olinjära laster", www.energimyndigheten.se

required: excess power from variable renewable sources generated at off-peak times can be stored and then used during peak demand periods.

- Increasing the amount of electrical energy that can be transmitted by modifying the protective algorithms that determine if a component has reached its maximum limit. Components are usually automatically disconnected by the protection if the current flowing through them exceeds a threshold value. It is not the current itself that determines if a component is overloaded, but the temperature of the component. Algorithms used today assume that a component's temperature is solely determined by the current flowing through it. If these algorithms are modified to take external factors such as outside temperature and surrounding wind speed into account, it becomes possible to allow higher currents when outside temperatures are very low or wind speeds very high.

3.4.2 Reducing peak load at system level

At system level the supply of power must match demand at all times. Large-scale conventional power plants deliver both active and reactive power, but in this discussion we only consider active power[18]. For active power, sufficient production capacity is required to:

1. Match total consumption. A portion of total consumption can be matched by power imported from neighbouring countries via DC or AC interconnectors. This of course requires that there is sufficient production capacity in neighbouring countries. Conversely, production capacity in Sweden can be used to satisfy demand in neighbouring countries. The spot market has mechanisms in place to ensure that the volume of electricity generators have contracted to produce and that suppliers have contracted to consume, match during every hour of the day following trading. Forecast errors are handled in the balance adjustment market and by Svenska Kraftnät's balance service.
2. Provide various kinds of reserve capacity. In the Nordic Region, there is rapid disturbance-reserve available to handle disturbances in the power system – i.e. unplanned events that cause power stations or lines to be abruptly disconnected from the network. Sweden has access to approximately 350 MWh of such reserve capacity according to agreements between the countries in the region[19]. An additional reserve of 250 MWh is available to handle consumption forecast errors, including forecast errors attributable to wind power. In addition, an additional 1 200 MWh must be available within 15 minutes to replenish the rapid disturbance-reserve in the entire Nordic region after the disconnection of a large power plant. This means that almost at all times, generating capacity must exceed expected demand by approximately 1 800 MW. Svenska Kraftnät is responsible for making sure sufficient resources are available. Svenska Kraftnät primarily buys this capacity on the open market,

[18] To deliver reactive power is just as important. The last two major outages in Sweden were caused by a lack of reactive power. The balance between generation and consumption of reactive power can be said to be equivalent to that for active power. The biggest difference is that the transport of reactive power causes much larger network losses. This means that it should be generated close to where it will be consumed.

[19] For more details on the different reserves in the Nordic electricity system see "Avtal om driften av det sammankopplade nordiska kraftsystemet (Systemdriftavtal)", available at www.entsoe.eu

but if the market cannot provide enough reserve capacity Svenska Kraftnät may access its own reserve capacity which consists of both generating capacity and contracts with industrial consumers to quickly reduce consumption if needed.

These two requirements hold at all times, including the hours of the year when consumption is at its highest levels. The reserve capacity must also be available even if several large production plants are not running because of repairs or maintenance work. The different kinds of reserve capacity and the highest expected level of demand together yield a requirement that total production capacity is at least as large as the sum of:

1. The highest expected level of demand several years into the future. Since constructing large power plants can take several years, it is important to look 5-10 years into the future. Ahead of every winter, Svenska Kraftnät estimates the margin between production and demand. For the winter 2009/2010 the worst-case demand scenario (a very cold, 10-year winter) was 27 600 MW.
2. The different reserves described above, totalling 1 800 MW
3. A margin to cover planned and unplanned generation outages. This margin can be computed in various ways. In the simplest model it is a fixed percentage of total consumption. Alternatively, a complex formula involving estimates of the reliability of every production plant can be used. Svenska Kraftnät uses a formula where it is assumed that production plants are unavailable 10 % of the time. Given a maximum demand of 27 600 MW and reserve capacity of 1 800 MW, this leads to a requirement that total production capacity must be at least 32 700 MW.

Summarizing: we have a total production capacity of 32 700 MW, a highest expected demand of 27 600 MW, and 5000 MW of production capacity is likely will never be used. This poses the problem of financing this spare capacity, as generators receive all their revenues from electricity sales. When the Swedish electricity market was deregulated in 1996, it was no longer financially feasible for production companies acting in a competitive market to keep power plants that were previously kept as part of the capacity reserves. To ensure security of supply, the Swedish Parliament therefore decided that Svenska Kraftnät would be allowed to procure reserve capacity for a maximum level of 2000 MW to be used in extraordinary circumstances if marked-based solutions cannot match production and demand. Parliament has recently decided that this mechanism will be phased out, and gradually replaced by demand response bids. The transition is expected to be complete by March 15th, 2020[20].

If security of supply can instead be ensured with smart technology, the need for 5 000 MW of capacity in excess of the highest level of expected demand can be reduced. However, it is important that the use of smart technology is combined with policies that provide sufficient incentive signals for market actors to maintain an adequate capacity margin.

[20] Law (2003:436) load reserve.

Transmission capacity is also finite. Transmission constraints limit the amount of electricity that can be transported between different parts of the country. Bottlenecks exist primarily between the northern and southern Sweden, but there are also constraints within southern Sweden, even if some of these will disappear when the planned southwest link (Sydvästlänken) is completed. This means that production has to match demand even within regions and not just in the country as a whole, so the location of the available generation and reserve capacity is relevant. Regarding transmission capacity, at least one reserve grid line is required at regional level under normal operation. During network planning it would be preferable to have two reserve grid lines to handle situations when long-running repairs have to be conducted on individual lines[21].

The classical solutions to peak load problems at system level is to bring in more generation capacity and to reinforce the transmission grid so that peak demand in one region can be more easily met by increasing generation in another region. However, in today's competitive market, decisions on how much generating capacity is needed are taken by those parties investing in new power stations, the exception being Svenska Kraftnät's capacity reserve, which is being phased out. Reinforcing the transmission grid to remove constraints is costly and time consuming.

A third way to tackle peak load problems is to reduce the size of the peaks by including a much greater role for storage and demand side measures. Pumped storage has already been mentioned, and there are a number of potential energy storage options currently being researched. However, as with generation investments, investments in storage are made on commercial terms. Storage facilities have fixed costs that must be recovered even when the facilities are not extensively used so storage might not make an economic case. This problem is not shared by the alternative – a more dynamic demand side. Participation of demand side resources as capacity reserve can be a very cost effective alternative as there are no costs associated with maintaining this reserve capacity even when it is only required to run occasionally. Some of the reserves held by Svenska Kraftnät are in this form. Svenska Kraftnät has load curtailment agreements with large industrial consumers that require these actors to reduce electricity consumption within a certain time limit if asked to do so by Svenska Kraftnät. The new smart grid technologies can be used to engage a wider set of consumers in such consumption reduction schemes. Demand response will be covered in more detail in section 3.7.

3.4.3 Network tariffs and transport capacity

More sophisticated network tariffs could be an important tool for shifting demand away from peak periods. Current network tariffs give no incentives to customers to act in ways that are beneficial to the system. The costs seen by customers do not reflect the actual load on the grid in any way. Advanced communication technology between generators, the grid, and customers offer the possibility of tariffs that reflect the costs of transmission and distribution at any one time.

[21] For more details on plans for the transmission grid, see "Avtal om driften av det sammankopplade nordiska kraftsystemet (Systemdriftavtal)", available at www.entsoe.eu

For instance, during periods with significant power flows from regional to local networks, network costs seen by consumers could go up. Conversely, when power flows are low, costs would be low. Such network tariffs would give consumers strong incentives to shift discretionary elements of electricity demand away from periods in which their local network has a high load. Power flows between grids are not entirely predictable and depend among other things on the weather, so continuous feedback on costs is needed if consumers are to get the right price signals. Information about variations in network tariffs could be provided through the electricity meters or in some other fashion.

Furthermore, load-based network tariffs would facilitate the large-scale introduction of renewable electricity production. Load-based network tariffs could be designed so that consumers are given strong incentives to shift demand away from periods with low local renewable electricity generation to periods with a local surplus of renewable electricity generation.

3.5 Energy efficiency

3.5.1 Network losses

Electrical losses are an inevitable consequence of the transfer of energy across electricity networks. In 2009, network losses in Sweden were 7.3 % of consumption[22]. Swedish network losses were distributed in the following manner:

- 2.8 TWh were lost during transportation across the transmission grid.
- 2.3 TWh were lost during transportation across regional networks.
- 3.9 TWh were lost during transportation across local distribution networks.

There are different ways to reduce losses. Network losses are proportional to the square of the current so greater utilization of the network's capacity has an adverse impact on losses. Reducing the current is a very efficient way to reduce network losses. The quadratic relationship between current and losses also means that it is profitable to distribute loads evenly over time. Another way to reduce losses is to reduce resistance in lines, cables and transformers, so that losses are reduced even if the current remains unchanged. For lines and cables this primarily involves increasing their cross-sectional area. For transformers, it is also possible to reduce losses that occur in the core of the transformer (iron losses) and that do not vary with current.

Since there is a relationship between voltage and current (which in turn is determined by loads) it is possible to control network losses by controlling voltage levels. Because at higher voltages a lower current is required to transport the same amount of electricity, moving to higher voltages will reduce usage and therefore losses on the networks. In transmission and regional grids voltage levels are therefore kept as close as possible to their maximum permissible values. The situation in local distribution networks is more complex. For some loads, a reduction in voltage levels leads to reduced currents, whereas the exact opposite is true for other loads.

[22] According to statistics from Svenska Kraftnät. Total demand for 2009 was 124 TWh. Network losses should be compared to the total generation from wind power in Sweden: 2,5 TWh in 2009.

3.5.2 Consumption information to consumers

Giving consumers access to detailed information about their consumption can indirectly support energy efficiency. The hope is that consumers will react to this information by adapting discretionary demand. Monthly feedback on consumption patterns can be useful, but in order to make informed decisions about their consumption, consumers will need consumption information broken down into intervals of one hour or less. Several network companies have started to provide such detailed information to consumers via web-based consumer portals. However, a study performed by a group at Lund University did not reveal any strong correlation between the existence of such information services and significant reductions in electricity consumption[23]. The study suggested that energy efficiency advisory services could be used to augment the value of the web-based hourly consumption information[24]. On the other hand, the Interactive Institute has shown in several studies[25] that with the right kind of real-time information feedback, it is possible to make consumers more aware of their consumption so that they reduce their overall consumption. The real-time feedback mechanisms also made consumers more engaged in energy efficiency issues. Measuring consumption in real time (for instance once every second) is most likely more cost effective if measurement data is only stored locally, either inside or just outside the actual meter that measures the amount of energy that flows from the grid to the consumption facility.

With the right kind of consumption feedback it becomes possible to reduce overall consumption by approximately 10 %[26]. If the goal is to give all consumers incentives to reduce consumption by such amounts, it will be necessary to provide not only the necessary consumption data, but also easily accessible energy efficiency advisory services.

3.5.3 Efficient consumption

There is also en energy efficiency trend in the consumer goods industry. Most electrical appliances as well as most consumer electronics products have become more energy efficient. A well-known example is the replacement of traditional light bulbs by low energy bulbs where 60 W light bulbs are typically replaced by either 40 W halogen lamps or 14-W low energy bulbs. Such replacements have the potential to reduce electricity use considerably. Increased use of more energy efficient appliances also leads to reduced network losses and reduced peak loads without a need to intervene in the electricity networks.

[23] Elin Ersson, El-info via digitala kanaler Potential att förändra elanvändning i bostäder. Case study 1 ”Min elförbrukning” carried out at Skånska Energi AB; LTH., February 2009. Case study 2 ”Dina Sidor” carried out at Öresundskraft, LTH, Maj 2009. Case study 3 ”EnergiDialog-Privat” carried out at E.ON Sweden AB, LTH, juli 2009.
[24] J. Pyrko, El-info via digitala kanaler Potential att förändra elanvändning i bostäder Syntes, Elforsk report 09:90, November 2009.
[25] L. Broms, et al., *Coffee maker patterns and the design of energy feedback artifacts.* In: DIS 2010, 16-20 August 2010, Arhus, Denmark. A. Gustafsson, Positive Persuasion - Designing enjoyable energy feedback, experiences in the home. PhD thesis, Dept Applied Information Technology, Chalmers, 2010.
[26] IEA Demand Side Management Propram, IEA Task XIX Micro Demand Response and Energy Saving; http://www.ieadsm.org/ViewTask.aspx?ID=16&Task=19&Sort=0

3.5.4 Electrification in the transport sector

Another way to reduce total energy consumption is to increase electrification in the transport sector. The assumption here is that the electricity used to power vehicles will have been produced in an environmentally friendly way[27].

A shift to electrification in transport will increase the strain on the electricity system since electricity demand will go up. In Sweden, total energy consumption in the transport sector in the year 2008 was 129 TWh, of which 88 TWh were due to the use of vehicles. A complete transition to electric vehicles would probably not increase the use of electricity by as much as 88 TWh, but it would still lead to a significant increase in the demand for electricity from current annual levels of approximately 150 TWh. Electrification in the transport sector is not expected to occur rapidly in the coming years with some estimates that about 15 % of all cars will be electrically powered in some form by the year 2020[28]. It is expected that the large majority of these cars will be hybrid cars that will reduce total energy consumption without causing total electricity consumption to rise significantly. Fully electric vehicles are only expected to be used for travelling relatively short distances. Based on these facts we estimate that use of electric vehicles will cause electricity consumption to rise by 5 TWh by the year 2020. This represents an increase of 5 %.

All forms of electric transportation share a common characteristic - they will lead to consumption that varies significantly over time and will place significant additional power demands on the grid. The amount of infrastructure reinforcement needed to accommodate this new demand can be reduced if it is managed intelligently by smoothing load peaks. Again, there are difficulties for grid operators to do proper network planning. It is currently not known how many electric vehicles will be connected to different parts of the grid[29]. It is also not known how often electric vehicles will have to be recharged. A number of studies from the US[30] show that some rural grids will become overloaded when as little as 2 % of all vehicles are electrified. The studies also show that the majority of today's grids are already capable of handling situations where as much as 20 % of all vehicles are electrified. The discussions from the previous section on reducing load peaks are relevant when discussing the impact of electric vehicles as well.

3.6 Active customers

Active customers can be defined as customers that actively engage in choosing between different suppliers or select different services or contract types from their existing supplier. Active customers are also those customers that try to cut the size

[27] What should count here is the energy source that is used to generate the extra electricity that is needed for electrification. On the open market, it is the most expensive, price-setting technology for the hour. There is no straightforward way to calculate the contribution of electrification towards decarbonisation, and the question is outside the scope of this report. In this report we concentrate on barriers to smart solutions that make it easier to integrate electric vehicles in the electricity system.

[28] As a comparison and according to the Swedish Transport Agency, the number of cars with catalyzers (compulsory for all new cars since the late 80s) increased by 5 % per year. The adoption of electric vehicles, which will be voluntary, is expected to happen at a slower pace.

[29] S. Babaei, Effects of plug-in electric vehicles on distribution systems - A real case of Gothenburg, IEEE PES Conf. on Innovative Smart Grid Technologies Europe. October 2010, Gothenburg.

[30] M. Duvall. Introduction to electric transportation, EPRI PQ and Smart Distribution Conference, June 2010, Quebec City, Canada.

of their electricity bill by measures other than merely reducing their consumption. This primarily involves shifting consumption from periods of high demand to periods of low demand. Active customers can also be customers that are willing to invest in control equipment that automatically adjusts consumption in response to external price signals, customers that elect to produce some of the electricity they consume themselves, or customers that are prepared to use energy storage technologies to shift consumption in time.

Electricity customers face significantly different situations when buying energy than when contracting network services. Network companies operate in a monopoly environment, whereas suppliers operate in a competitive market and customers are free to select any supplier they want, and to select among different offers from individual suppliers. The Inspectorate runs a web-based electricity price comparison application called "Elpriskollen" (The Electricity Price Guide)[31] that allows customers to make easy comparisons between the different deals offered by suppliers.

The most important types of contract available to customers are:

- Variable price contracts - the monthly price is based on an average of the spot prices for that month.
- Fixed-price contracts - the price is fixed for a time period ranging from six months to three years.
- Open-ended contracts - This is the default contract type that consumers that have not made an active choice get.

Several suppliers also offer packages where customers can choose how the electricity they consume is generated.

The metering reform, requiring network companies to read electric meters on a monthly basis, has made it easier for electricity customers to switch suppliers. When/if hourly meter readings are introduced new contract forms should appear, giving consumers even greater choice.

Network tariffs offer customers less choice. Maximum demand tariffs are determined by the customer’s peak (maximum) power demand and are available at different voltage levels. Time of Use (TOU) tariffs set different rates according to fixed hours of the day to motivate customers to shift consumption away from peak periods. Load tariffs are calculated by looking at the (three) maximum demand readings, and averaging the total. Load tariffs are based on the average of the highest demand readings during one month and are designed to give customers incentives to distribute loads as evenly as possible in order to minimize their individual loads peaks and therefore the amount that they pay. Some network companies also offer a contract by which customers agree to a certain peak power demand, and pay a penalty if their load exceeds this threshold value.

[31] http://www.energimarknadsinspektionen.se/elpriskollen/

Load tariffs require hourly meter readings. Some network companies already support hourly meter reading for all their consumers and are thus able to offer load tariffs to households. Some possible load tariffs are:

- The price is based on the largest hourly consumption for a year or a month.
- The price is based on the largest hourly consumption during peak hours (such as week days between 07:00 and 20:00) for a year or a month.
- The price is based on the load in the local distribution network.

The main reason for distribution companies to offer load tariffs is that they themselves are subject to such tariffs at the point where the local distribution network connects to the regional network. Distribution companies may also want to reduce maximum load in their network in order to avoid or postpone grid reinforcements.

3.7 Controlling power flows

The previous section described why it is relevant to manage demand and generation in parts of the grid, or in the grid as a whole. The reasons include:

- Reducing local or national production deficits by decreasing consumption and/or increasing production in parts of the grid.
- Increasing consumption to reduce a local surplus of renewable electricity.
- Minimizing network losses by increasing consumption during one part of the day while reducing consumption in another part.
- Using consumption reductions for capacity reserve purposes.

Demand can be reduced in various ways:

- Reducing consumption or disconnecting loads on orders from the system operator. Two examples of this phenomenon are rotating interruptions and under frequency load shedding. Rotating interruptions are planned in a certain way and have been designed to ensure security of supply under extreme conditions. Under-frequency load shedding is automatic and is a last line of defence against system collapse when a large shortage of production occurs.
- Reducing consumption or disconnecting loads for consumers with agreements with the system operator. These consumers are paid by the system operator to accept service disruptions when there are severe shortages of electricity. Parts of Svenska Kraftnät's capacity reserve are made up of such contracts. The customers that sigh such contracts (usually large industrial customers) should be prepared to suffer supply interruptions, or they should rely on standby power plants that are situated at their premises.
- Managing demand through price signals. When generation is scarce, hourly spot prices rise giving customers that are exposed to spot prices an incentive to reduce their consumption. Some large industrial customers have such dynamic pricing contracts, but smaller customers do not. The load-based network tariffs that most large customers have provide strong incentives to reduce load peaks at any given time, but not necessarily when the system needs it.

In order to engage a wider set of customers in demand side management, new commercial arrangements must be established. Electricity suppliers currently offer small customers a number of different contract models that are based on the derivatives market, the spot market, and the balancing market. At present it is not possible for small customers[32] to buy electricity at a price that changes by the hour, let alone in real time. Until recently, this restriction has been a necessity, but the ubiquity of personal computers and of broadband access, and the introduction of smart meters has made it technically feasible to offer dynamic tariffs even to small customers. If ways are found to use the demand response potential of small customers, and if suppliers promote commercial arrangements for demand management, it may be perfectly possible to allow small customers to contribute to demand peak reduction schemes by being active players in the electricity market. In the long run, it may also be possible to let small customers participate in balancing markets and markets for ancillary services.

The classical objection to households assisting system balancing is that households and other small customers are too small to matter to the system as a whole. However, small loads can be aggregated and can be treated as a single unit and because residential electric heating is a major contributor to demand peaks on cold winter days, the contribution from households to smooth out peaks across the day could be significant. Furthermore, increased automation means that washing machines and dishwashers could be set to run according to the hourly price of electricity. Many household loads are indeed unimportant for load peak reduction purposes. Switching off lights or TVs could only be of use in extreme situations that may appear as seldom as once every ten years. Domestic consumption's potential will only increase with the likely electrification of transport.

As mentioned before, peak demand reductions can either be achieved by reducing consumption during peak times, or by shifting consumption to off-peak periods. Reducing consumption for certain customers to very low levels can be justifiable during periods when generation is scarce or during grid congestion. Such reductions are an alternative to rotating interruptions and would be a refinement of the Swedish Energy Agency's Styrel project[33]. Shifting consumption to off-peak periods is not as disruptive for customers and reduces the immediate need for new generation capacity or grid reinforcements. It is for schemes of this second kind (load shifting) that household loads such as washing machines, electrically heated houses, and electric vehicles can be used.

In order to use the full potential of these loads, the following is required:

- Appliances that can be remotely controlled and/or configured to react to price signals.
- Electricity prices and network tariffs that at all times reflect the system's generation and transmission capacity
- A communications infrastructure that can distribute price information to appliances.
- High frequency (e.g. hourly) consumption metering so that customers can be properly settled.

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[32] In this context, small consumers are domestic consumers and SMEs.

[33] Styrel: Styrning till prioriterade användare vid elbrist. http://www.energimyndigheten.se/styrel

Expected local or national surpluses of renewable electricity can be avoided by shifting demand from periods with a deficit of electricity from renewable sources to the period with an expected surplus. However, this is not always possible, and generation may have to be curtailed. This can be achieved by applying information and communications technology to the grid to allow operators to monitor the networks and control the output of increasing numbers of small-scale generating units, possibly located at consumer's premises.

All over the world a large number of research projects are looking into technologies for controlling both generation and demand. Especially noteworthy for the development of distributed electricity generation from renewable energy sources are microgrids and virtual power plants (VPPs).

A microgrid is a small-scale network that includes generators (often solar power and small-scale CHP), controllable loads and often storage devices. The microgrid is owned and operated by the customers that it serves, and it has the capability to control the balance of generating capacity and demand within the confines of the microgrid itself. While a microgrid can function in island-mode, it is normally connected to the distribution network. During off-peak periods or when electricity is otherwise cheap, microgrids can buy electricity at market rates. During peak periods the microgrid meets its demand with its own generating capacity or it may sell power back to the larger grid if regulations allow it. The microgrid concept is currently being actively developed in several EU-wide projects[34].

A VPP aggregates the output from many small generating units together, and acts like a single power plant when offering supply to the market. It is a potential approach to integrating distributed resources into power system operations. For instance, a VPP could be composed of several hundred households equipped with solar panels on their roofs in the south of the country, a number of wind power plants located in the north, 10-20 household consumers living in detached houses, a number of small commercial consumers located in a city, and a large industrial consumer with its own energy storage facilities located in the middle of the country. This portfolio of aggregated distributed units would then act as a single actor on energy and balancing markets on similar terms as conventional transmission-connected generation. However, since a VPP can be spread over a large geographical area, its usefulness for load shifting purposes may be restricted by congestion in the grid.

The strains on the grid can be reduced in several ways. Consumption can be increased or reduced, and production can be reduced. Sometimes it makes sense to reduce consumption during part of the time, and to reduce production during other times. Such multi-measure policies can be conveniently implemented using energy storage. The storage can absorb energy when there is surplus and release energy when there is a deficit. Private energy storage facilities can be used by customers that want to be able to buy electricity when it is cheap and use it whenever it is needed. However, energy storage facilities can also be placed at various places on the grid to improve the way the grid itself works. For instance, large-scale use of energy storage in local distribution grids could reduce the need

[34] Among which "Microgrids" and "More Microgrids". See http://www.microgrids.eu

for advanced metering functionalities (such as interval metering and two-way communication) for household consumers.

3.8 Summary and conclusions

In the transition towards a sustainable energy system, the electricity grid is both a barrier and a facilitator. This chapter has described various grid-related barriers to a large-scale rollout of renewable electricity generation. Some of these barriers can be overcome with new transformers, overhead lines and cables. However, new technologies can be used to remove these obstacles in a faster and more cost-effective way. These new technologies go under the name smart grids or intelligent networks.

Some of the new solutions are purely technical in nature. They include the use of power electronics to reduce the risk for overvoltage when microgeneration facilities are connected to local distribution grids, the use of communications technology to reduce protection errors, and the use of energy storage in various parts of the grid to balance local generation and demand. Other solutions need active consumers that react to price and load signals. The goal is to give customers strong incentives to reduce their consumption during high load periods, contribute towards system balance or with reserve capacity. These market-based solutions will require detailed measurements of the consumption of individual customers and a communication infrastructure that enables efficient communication between producers, grid operators, and consumers. In other words, there is a need for smart metering, hourly measurements and communication infrastructure.

The market-based solutions that rely on active customers will in many instances require fine-grained (hourly) interval metering of consumption. The Energy Markets Inspectorate has paved the way for such a development through its proposals for hourly meter readings for household consumers.

4 Current situation

This chapter provides an overview of smart grids and smart metering activities and initiatives taking place in Sweden as well as in other countries. We focus on larger-scale development and demonstration projects on smart metering and smart grids. A few research projects taking place at Swedish universities and research institutions will also be covered.

The content of this chapter is based mainly on information gathered from meetings of the project reference-group, bilateral meetings, direct interaction with representatives of some of the groups whose work is being described in the chapter, and through literature studies. This chapter is not a comprehensive survey of all activities and initiatives currently underway in Sweden or elsewhere. Compiling such a comprehensive survey has been outside the scope of this project.

4.1 Facilitate increased amount of electricity generation from renewable energy sources

It is important to distinguish between measures that are designed to increase the use of electricity generated from renewable energy and measures that are designed to make it easier to connect large amounts of electricity generation from renewable energy sources to the grid while ensuring quality and security of supply. The term "hosting capacity" is used to describe the amount of electricity generation from renewable energy sources that can be connected to the network before quality and security of supply are compromised.

This chapter will identify new technologies - smart grids and smart metering - that can be used to increase the hosting capacity of an electricity network. Hosting capacity can also be improved in more conventional ways, but conventional measures to improve a network's hosting capacity will not be discussed in this chapter.

4.1.1 Requirements on generating plants

As the proportion of generation from renewable sources increases, it may come to present a problem for the transmission grid. To maintain a secure, reliable and high quality system, Svenska Kraftnät places strict requirements on generators that are connected to the grid, especially large generators connected directly to the transmission grid. These requirements cover aspects such as how the plant behaves under both normal and abnormal conditions, and how the plant provides ancillary services such as reactive power compensation, that are needed to balance and regulate the transmission grid. These requirements are mandatory in Sweden and are subject to a regulatory framework[35].

[35] Affärsverket SvenskaKraftnäts föreskrifter och allmänna råd om driftsäkerhetsteknisk utformning av produktionsanläggningar, SvKFS 2005:2. http://www.svk.se/Tekniska-krav/Foreskrifter/

Other countries also place requirements on generators that provide ancillary services in order to guarantee grid safety, reliability, and voltage quality. European standard EN 50438[36] is an attempt to harmonize requirements on small production units (no more than 16 A per phase, connected to the low voltage networks), but with room for country-specific requirements. ENTSO-E are working on producing a similar standard for generation plants that are connected at a voltage level of 100 kV or higher[37].

Placing requirements on electricity generating plants does mean using new technology, and does not fall under the concept "smart grid". However, these requirements have encouraged technological developments and research into how large wind farms are best connected to the grid. Some of the development and research work described below is focused on these requirements.

4.1.2 Reinforcement of the transmission network

In Sweden, the reinforcement of the transmission grid and of the interconnection capacity with neighbouring countries continues. In addition to the already mentioned southwest link, links are being built between Ekhyddan and Barkeryd, Stenkullen and Lindome, as well as a second HVDC link to Gotland. Important projects to strengthen interconnections with other countries are Fenno - Skan 2 (Finland), Nordbalt (Lithuania), and Järpströmmen - Nea (Norway). This will result in a certain load reduction during peak loads[38].

Further links between Scandinavia and continental Europe are also planned, although when, and if, these will be completed is as yet uncertain. These include a second cable between Norway and the Netherlands, a fourth cable between Norway and Denmark, and a cable between Norway and Germany. The main purpose of these cables would be to balance intermittent renewables in the continent with hydropower available in Scandinavia. Another project worth mentioning is the Kriegers Flak offshore wind park that will be connected to Denmark and Germany via HVDC links, and which may be connected to Sweden in the future.

Also in Europe there is a significant need to reinforce the transmission network. Investments most likely to come forward are HVCD links between countries. There are plans for HVDC links between the UK and the Netherlands, between Belgium and Germany, and between Spain and France. Strengthening the national transmission grids is just as important and a prerequisite for integrating the Nordic electricity market with electricity markets in continental Europe, making it possible to use hydropower in Scandinavia and central Europe as balancing support for wind power. The European Network of Transmission System Operators for Electricity (ENTSO-E) published in June 2010 the Ten-Year Network Development Plan 2010-2020[39] to address the urgency of building the transmission lines necessary to enable the achievement of European climate change goals. The plan identifies the massive renewable integration in both northern and southern Europe

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[36] Requirements for the connection of micro-generators in parallel with public low-voltage distribution networks, EN 50438: 2007.

[37] Requirements for Grid Connection Applicable to all Generators, working draft, 1 October 2010.

[38] For descriptions of these projects see http://www.svk.se

[39] Ten-year network development plan 2010-2020, ENTSO-E, 28 June 2010.

as one of the main drivers for grid development. For Sweden, the Plan identifies the need for north-south grid development.

Sweden has been at the forefront of HVDC technology and other technologies to increase transmission capacity through research at KTH and Chalmers, and has world-leading firms in this sector like ABB.

One way to increase transmission grid capacity without building new cables is to convert AC cables to DC by changing the isolators. This conversion can more than double transmission capacity. A working group within CIGRE is developing guidelines for how to carry out the conversion[40]. The conversion can be performed while the cables are in use, so the availability of the grid will not be adversely affected[41].

Visions for a pan-European transmission grid that goes beyond the current 400 kV grids that connect different countries and regions have existed for a long time. The current European electricity grid was built mainly to allow countries to support each other during temporary generation shortfalls in individual countries or regions. This grid is currently being used to create a common European electricity market, and this is not sustainable in the long run. The development of a pan-European electricity market, massive integration of renewables especially wind, and uneven levels of investment in new production capacity in different parts of the continent have together led to a situation where the amount of electricity that is transported through European electricity grids is much larger than the transmission grids were originally designed for. A new pan-European transmission grid will either be an AC grid at higher voltage levels (800 kV for instance), or a DC grid (HVDC)[42].

4.1.3 Research and development in Sweden

Research and development on the use of smart grids to increase hosting capacity is to a large extent still in its infancy.

At Lund University research into microgrids has been going on for some years. One of the goals of microgrid technology is to facilitate the integration of generation from renewable sources at low voltage levels. Microgrids was one of the research areas examined by the European Distributed Energy Partnership (EU-DEEP)[43] - in which STRI in Ludvika and Lund University participated. In the project, the Swedish participants were involved in several aspects of network planning, such as voltage control, power quality, relay protection and operation of microgrids. The project studied different mechanisms to integrate renewable and CHP generation into electricity grids and electricity markets. The project also developed the concept of hosting capacity (see Figure 3.1) that is now considered

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[40] CIGRE Working Group B2.41, Guide to the conversion of existing AC lines to DC operation. Convenor: Jan Lundquist (Sweden).

[41] The conversion from AC to DC itself takes only a few hours, but test-running the HVDC link can take some weeks, before the link can be used to its full capacity. In the future and with more experience, test runs will probably be completed faster [Jan Lundquist, STRI].

[42] Details on such a network are available at G. Asplund, Continental overlay HVDC Grid, CIGRE Sessions 2010, paper B4-109.

[43] http://www.eu-deep.com

an important measure for determining the performance of the intelligent grids of the future.

Chalmers University of Technology in Gothenburg has carried out research on wind power for a long time and has explored some aspects of how wind power is integrated into electricity networks. Similar research has been carried out at the Norwegian University of Science and Technology (NTNU) in Trondheim in Norway. Both Chalmers and NTNU focus on power electronics, FACTS and HVDC and have also looked into the feasibility of using wind power to provide reactive power as an ancillary service[44]. A number of recently started research projects at Chalmers focus on technologies that facilitate connection of renewable electricity production plants into electricity grids.

The Power Systems group at The Royal Institute of Technology (KTH) in Stockholm conduct research into electrical power systems and are currently developing methods to integrate large amounts of intermittent generation. There are also a number of KTH projects on the use of power electronics control technology to increase the transmission capacity of transmission grids using technologies such as HVDC.

KTH is also an important partner in the European Institute of Innovation and Technology (EIT)'s KIC InnoEnergy Consortium[45]. The consortium has 30 partners grouped into six nodes: Sweden, Poland, Benelux, Iberia, Alps Valleys, and Germany. The Swedish node is responsible for the area Smart Grids and Energy Storage. Other Swedish participants are Uppsala University, Vattenfall and ABB.

A collaborative research project between STRI and Luleå University of Technology (LTU) studies how communications and storage technologies can be used to increase hosting capacity in distribution networks. The project is part of the Ludvika High Voltage Valley programme. KTH and Uppsala University are also participants, with KTH specializing on communications infrastructure and Uppsala on storage technologies. LTU has also recently started a new wind power research centre where integration of wind power into power grids is one of the research areas.

Vattenfall Research and Development participates in the European Active Distribution network with full integration of Demand and distributed energy RESourceS (ADDRESS)[46] project that studies mechanisms to make household consumers and small commercial consumers more active participants on electricity markets. The project studies how consumption and microgeneration can be controlled so that net consumption and net production are optimized. Such coordination between consumption and production, together with the creation of new markets for electricity and ancillary services, are seen as important measures to integrate large volumes of renewable electricity production in low voltage distribution grids.

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[44] N.R. Ullah, K. Bhattacharya, T. Thiringer, Wind farms as reactive power ancillary service providers - Technical and economic issues, IEEE Transactions on Energy Conversion, Vol.24, no.3, September 2009.
[45] http://www.innoenergy-initiative.com/
[46] http://www.addressfp7.org/

Vattenfall are carrying out a project that aims to increase transmission capacity of 130 kV cables during periods with high wind speeds. If large amounts of wind power are connected to regional networks, the cables in those networks will be heavily loaded during periods with high wind speed. By carefully optimizing the capacity of the cable during such periods it becomes possible to increase hosting capacity and harvest more power from the connected wind power plants. This method is in use by E.ON in Germany where carefully placed sensors are used to compute the transmission capacity of cables in real time. STRI has developed mathematical methods that can be used to judge how profitable such dynamic load capacity technology is. STRI has developed these methods as part of Elforsk’s risk analysis programme.

Several research, development, and demonstration projects to test technologies that facilitate large amounts of renewable generation being connected to the grid are being planned in Sweden. The most prominent project is the Stockholm Royal Seaport project (also known under the Swedish name "Norra Djurgårdsstaden"). However, from a power-engineering point of view the project is still in a very early stage: a pre-study into requirements and design choices for a large-scale smart grid in an urban environment is currently under way. The project has the following main research areas:

- Active, solar powered buildings
- Rechargeable electric cars
- Energy storage and smart appliances
- A port where electric ships are connected to the main electricity network with supporting power electronics equipment
- Identifying and studying of new measurement systems with both active and passive components to reduce the grid’s maintenance and capital costs while ensuring quality of supply
- Requirements on future market models and regulatory frameworks for electricity distribution

The project focuses on active consumers and reduction of peak loads. It aims to show how one part of a city can contribute to the stability of the overall electricity system. The project is a collaborative effort between Fortum and ABB.

Vattenfall and ABB are looking at ways to connect large volumes of wind power on the island of Gotland. The aim is to find solutions to stability and reliability problems that occur when large volumes of wind power are connected to rural grids. The technologies studied include network automation, energy storage, and demand response. Falbygden Energi are studying how active and reactive power can be controlled in 20 kV grids with a surplus of wind power. There are also plans for a smart grid in the west port of the southern city of Malmö. Finally, STRI in Ludvika and VB Energi are planning to test load management on hydropower and wind power in Dalarna.

ABB in Västerås are developing a product that combines an SCV Light converter with battery-based energy storage, and which is primarily intended to be used with intermittent generation. This is yet another example of how development projects are driven by requirements that are being placed on generation facilities.

In this particular solution, intermittency is handled by storing excess energy in a storage that is part of the generation plant itself. It is not evident that this is the optimal solution for society as a whole. It might make more sense to modify electricity networks so that the grid can handle the intermittent production from several power plants.

4.1.4 International research and development

A concrete example of how smart grid technologies are being used can be found in Japan, in a neighbourhood where 2 129 kW of solar power are spread over 553 facilities. Every house in the neighbourhood is equipped with battery storage that can receive or inject 4 kW, the maximum power of the solar panels over a 70-minute period, in order to even out fluctuations in the production from the solar panels. The batteries are used to prevent overvoltage and overload in the local distribution network. Each household gets an extra 2.2 kWh solar power per day that has been stored in the batteries. Losses in the batteries are 0.8 kWh per house per day. The benefit to society is therefore 1.4 kWh per house per day[47]. Battery storage is also used in a larger facility in Japan that has solar panels with a capacity of 2 000 kW and storage capacity of 500 kW for up to seven hours. The storage facility can be used to handle fluctuations in output that have duration of one hour or less, due to cloudiness.[48]

Energinet.dk, the Danish Transmission System Operator, has developed a control system that keeps reactive power flows between local distribution networks and the transmission grid constant. The control system is installed in 150/60-kV transformers and communicates with all power plants situated on the low voltage side of the transformer (10 and 60 kV). The control system receives information from the production plants and sends control orders back. One test of the control system was performed in 2008 in a grid with 10.8 MW CHP and 4 MW wind power. A larger test was performed in November 2010 in a grid with 28 000 consumers, four CHP plants and 47 wind turbines. A full-scale test is planned for 2011. [49] [50]

The European project "More Microgrids" has built an experimental pilot facility for load management on a Greek island with twelve houses, 10 kW solar cells, 53 kWh battery storage and one 5 kW diesel generator. The load management system uses power line communications to remotely control switches. The power output from solar cells and storage facilities is optimized by controlling the use of water pumps. The same technology was used to create a virtual power plant in the EU-DEEP project. This EU-DEEP system is composed of 80 kW CHP, 23 kW solar cells, 5 kW battery storage, 20 kW heat pumps, and 3 kW additional controllable load.

[47] Asahiko Tokuoka, Large scale DER integration experiments in Japan, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.
[48] ibid.
[49] Per Lund, Cell controller pilot project – Intelligent mobilization of distributed power generation, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.
[50] Verdens største intelligente elsystem testet i Danmark, 12 November 2010; http://www.energinet.dk/

Different scenarios such as inflexible production with controllable load, and inflexible load with controllable production are being studied[51].

The objective of the European FENIX (Flexible Electricity Network to Integrate the eXpected "energy evolution") is to boost distributed energy resources by maximizing their contribution to the electric power system, through aggregation into large-scale virtual power plants and decentralized management. The project is planning a pilot project in northern Spain where twelve CHP plants, two wind farms, five hydropower plants and eight solar plants will be combined into one virtual power plant. The capacity of individual generators varies from 100 kW to 50 MW with a total capacity of 167 MW. This collection of power plants will act as a single entity and provide various services in a variety of markets: balancing power, capacity reserves, reactive power, voltage control and reserve power to support the distribution network when important local components fail[52].

The European project "More Microgrids" mentioned above has eight demonstration projects underway to examine technologies for adding small-scale, renewable generation to electricity grids in general and local distribution networks in particular. The demonstration projects are:

- Derio, Spain: 5.8 kW solar power, 50 kW CHP, 6 kW wind power, 250 kW controllable load.
- Kythnos, Greece (see above)
- Ilhavo, Portugal: 60 kW CHP and controllable load in the form of air conditioning, water pumps, and lightning for an indoor swimming pool.
- An area in the Netherlands containing 200 solar panel equipped summer houses with a total capacity of 315 kW
- Mannheim-Wallstadt, Germany: a residential area with 31 kW solar power and 40 kW CHP.
- Italy: 34 kW solar power, 125 kW CHP and various battery storages units (total 216 kWh; max power 306 kW)
- Bornholm, Denmark: the largest microgrid in the project with 30 MW wind power in a grid with maximum capacity of 55 MW[53]
- Kofuz, Makedonien: an agricultural facility with CHP and solar power

In order to handle wind power's intermittency it has been suggested that large-scale pumped storage are set up in conjunction to wind farms that are close to the Danish shore[54]. Rather than using two reservoirs, which is a commonly used technique in pumped storage, an underwater reservoir where the water level is changed is used.

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[51] Nikos Hatziargyriou, Aris Dimeas, Smart agent technology to help DER integrate markets: experiments in Greece, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.

[52] Tomás Gómez, Changes needed in the current network regulation to effectively integrate distributed generation in the distribution networks, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.

[53] www.energinet.dk/EN/El/Nyheder/Sider/Tomorrow%27spowersystemintheislandofBornholm.aspx

[54] Green power island: a vision for renewable energy storage; Planet Save, 5 August 2010. http://planetsave.com/2010/08/05/green-power-island-a-vision-for-renewable-energy-storage/

ERDF, in charge of operating France's public distribution network, is developing three new automatic distribution network control functions to better integrate more renewable generation[55]. The idea is to increase the monitoring of distribution networks and to use the information gathered for active voltage control.

4.1.5 Overview of ongoing research

All over the world there is ongoing research into how to best integrate electricity generation from renewable energy sources to the electricity network. Such research usually focuses in specific problems that appear when renewable generation plants are connected to electricity grids in general and medium and low voltage electricity networks in particular. Here are some of the research areas that are being pursued[56]:

- Power electronics control, energy storage, and the use of controllable generation and controllable demand to minimize risks for overload and overvoltage in local networks.
- Large-scale use of energy storage for balancing purposes and for compensating for wind forecast errors.
- Advanced methods for voltage control in distribution networks, including more efficient use of tap changers, increased metering in distribution networks, and using locally connected generation for voltage control.
- Advanced protective systems to avoid surges caused by the presence of generating units directly connected to the local network. This involves using protection systems at lower voltage levels than normal. There is also ongoing research into using data from various metering points in the grid to continuously compute optimal threshold values for all protection relays in the grid
- New methods for detecting the unplanned islanding of local networks with connected generation. This includes both passive methods (such as rate-of-change-of-frequency relays[57]), active methods (where a signal that becomes heavily distorted only during islanding is injected into the grid), and methods that rely on remote communications.
- Development of automatic control and power electronics methods to facilitate the operation of large-scale wind power plants in the event of network disturbances (fault-ride-through)[58].
- Research into how technologies such as HVDC and FACTS can be used to increase the transmission capacity of transmission grids. Generally this research is not focused on how renewable generation can best be connected to electricity grids, but results from this research can be relevant, e.g. research on multiterminal DC grids[59].

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[55] S. Grenard, New automation functions under development to enable French distribution networks to integrate efficiently large share of dispersed energy resources and renewable energy sources, CIGRÉ Sesssions 2010, paper C6-101.
[56] The examples come from "Math Bollen, Fainan Hassan, Integration of distributed generation in the power system", Wiley - IEEE Press, in press. More details and references available in that publication.
[57] ROCOF
[58] The objective is to pass the network operator's requirements; an installation's ability to withstand faults in the networks is referred to as ”fault-ride-through”.
[59] ”HVDC grids”

A number of large European transmission and distribution grid operators (including Swedish Vattenfall Distribution) that are active in the European Electricity Grid Initiative (EEGI) recently conducted a study to identify areas that require further research. Below are brief descriptions of some of the research projects that focus on how renewable electricity production plants can be connected to the grid (amounts within parentheses are estimated project budgets):

- "Advanced tools to analyse the pan-European transmission network expansion options according to energy scenarios for Europe" (21 M€),
- "Integration of small renewables in the distribution network" (90 M€),
- "System integration of medium size renewables" (150 M€).

4.2 Reducing peak load

As described above, the size of the expected peak loads sets requirements on transmission and generating capacity. Consequently, reducing peak load has always been of interest.

Rather than building new generating plant or reinforcing network infrastructure to handle the largest loads, it is possible to encourage customers to conserve energy when the grid is at or near its capacity. Two-rate tariff structures that differentiate off-peak from peak periods were offered by some Swedish network companies as far back as the 1940's, as well as tariffs structures in which the price per kWh increased when the customer's load exceeded a predefined threshold value[60].

Reinforcing the transmission grid (see Section 4.1.2) also contributes to load reduction during load peaks, as well as some of the research and development projects described in Section 4.1.3 and 4.1.4.

4.2.1 Tariffs and contracts

Some electricity suppliers in Sweden offer Time-of-Use (TOU) tariffs under certain circumstances.[61] [62] [63] Consumers are charged different rates depending on when they use electricity. Usually there are two time periods, peak and off-peak (or low price and high price as they are known in Sweden).[64] [65] The peak period occurs on weekdays 06:00-22:00, November to March. However, the number of suppliers that offer TOU tariffs has decreased in recent years.

A few suppliers offer time-dependent transmission tariffs to customers belonging to certain network companies. In such cases, the variable part of the transmission tariff has two different pricing structures depending on whether consumption happens during peak or off-peak periods.

[60] Gunnar Reiland, Elektriska maskiner och anläggningar, AB Nordiska Bokförlaget Erdheim & Co, Stockholm, 1943, s.460-472
[61] http://www.vattenfall.se/sv/tidstariff.htm
[62] http://www.karlshamn.se/KarlshamnEnergi/Privat/Vi_erbjuder/Elhandel/Vara_priser2/
[63] http://www.el.herrljunga.se/prislista.htm
[64] http://www.affarsverken.se/Privatkund/Produkter_och_tjanster/El/Elnat/Natavgifter/
[65] http://www.alvestaenergi.se/content-01.asp?pageid=100400301

Interruptible boiler contracts are contracts to curtail load developed for households that use both oil and electricity to heat their homes. Depending on constraints on the network, customers switch from using electricity to using oil for heating purposes. Customers receive a reduction in the levies charged to use the networks and give the local distribution network operator or the system operator the right to disconnect their electric heaters during periods with capacity constraints to help maintain the reliability of the electricity system. However, as consumers move away from oil-based heating and rely entirely on electricity, this contract is becoming increasingly rare.

- Skellefteå Kraft has an interruptible boiler contract for businesses with a demand of over 50 kW connected to the low voltage grid. Boilers have to be disconnected within two hours even outside working hours. Customers on this contract pay 10 500 SEK/year plus 4.8 öre/kWh[66] (100 öre = 1 SEK) compared to the standard price of 18 300 SEK/year plus 12.54 öre/kWh, or 28 600 SEK/year plus 3.09 öre/kWh.
- Vattenfall has interruptible boiler contracts in southern Sweden. Customers pay 7 200 SEK/year plus 11 öre/kWh during peak hours and 4 öre/kWh during off-peak hours compared to the standard price of 18 000 SEK/year plus 35.6 öre/kWh during peak hours and 9.2 öre/kWh during off-peak hours. Peak hours are weekdays 06:00 to 22:00 November to March.

Interruptible contracts are voluntary, but customers who have agreed to interruptible contracts cannot opt out of disconnection. The sum of these contracts represents a well-defined demand side capacity reserve. However, it is worth noting that how large this reserve actually is at any given time depends on outside temperatures, which makes that it is mainly available during the winter. Interruptible contracts have the advantage that customers have to reduce their consumption only when the system is tight. However, the effects of interruption can be considerable as electric heating is switched off. Interruptible contracts must therefore clearly state that they are only suitable for customers that have alternative means of heating at their disposal.

Load tariffs are another way to reduce peak load. Customers are charged according to their highest demand during a certain time period, e.g. a month. Most Swedish network companies offer load tariffs to large energy intensive customers. Local distribution networks pay load tariffs to use the regional networks.

- Starting January 1st 2011 Göteborg Energi will introduce a load tariff for both low and high-voltage business customers with fuses of 80 A or over. Customers connected to the low voltage network will pay 4 700 SEK/year plus 6,80 öre/kWh plus 35,80 SEK/kW/month[67]. The load component (SEK/kW/month) for each month will be based on the highest hourly demand the customer had the previous month. Göteborg Energi will evaluate whether load tariffs help flatten peak demand and decide whether a TOU component is desirable. The company intends to introduce similar contracts for domestic and smaller business customers.

[66] All tariffs are before taxes and regulatory charges.

[67] http://www.goteborgenergi.se/Foretag_Elnat_Elnat_i_Goteborg_Elnatsavgifter_2011_Nya_avgifter_DXNI-10269820_.aspx

- For the past ten years, Sollentuna Energi has been applying load tariffs to all customers, including domestic customers[68]. The fixed fee is 750 SEK/year[69] for apartments without electrical heating, and 1 500 SEK/year for all other customers with fuses of up to 25 A. The load component is calculated by taking the average of the three hours of the month with the highest demand, between 07:00 and 19:00 on weekdays. Customers pay 84 SEK/kW/month from November to March and 42 SEK/kW/month from April to October.
- Sala Heby Energi applies load tariffs for all customers with the exception of domestic customers in apartment buildings[70]. The fixed fee depends on the size of the fuse: 735 SEK/year for 16 A; 1 320 SEK/year for 20 A; and 1890 SEK/year for 25 A. The load component is based on the five hours with the highest demand, between 07:00 and 19:00 on weekdays: 89 SEK/kW between November and March and 31 SEK/kW between April and October.

The above-mentioned contracts give consumers financial incentives to change their demand patterns and smoothen their demand peaks. However, there is no clear incentive for customers to reduce demand when the system is tight so load tariffs cannot be counted to help maintain reliability of the electricity system. Adding a TOU component to the tariff can encourage consumers to shift discretionary demand to off-peak periods.

From the point of view if the network companies, load tariffs have the advantage that they do not require any extra equipment for load management. However, they do require hourly metering.

4.2.2 Other methods to reduce peak load

Some Swedish network companies have teleswitching functionality to remotely "switch" a consumer's electricity supply. For example, in the 1960s Jönköping's network company implemented a teleswitching programme to control electric heating, electric boilers, hot water heaters, tariffs and street lighting. The main reason for installing this equipment was to reduce load at supply points from the regional network in order to reduce the load fees it paid to the regional network company. The technology could be used to control a total load of 40 MW, divided into eight groups and including the electric heating of 10 000 households. However, the equipment has not been used for many years[71].

The 1 892 MW peak load reserve Svenska Kraftnät procures for the winter period includes consumption reductions. For the winter 2010/2011, 583 MW are in the form of consumption reductions. These are contracts with large electricity intensive customers (pulp and paper industry, metal processing industry, and the petrochemical industry) to reduce load. Load reductions include 70 MW generating plant located at the premises of large industrial consumers[72]. This plant primarily exists to provide standby generation, but it can also be run at times when the grid is under severe stress. Such an increase of generation is actually viewed as

[68] http://www.sollentunaenergi.se/elnat/goto/natavgifter.htm
[69] Prices for domestic customers include VAT but do not include regulatory charges.
[70] http://www.sheab.se/index.php/elnat/natpriser/
[71] Demonstrationsprojekt Effektstyrning på användarsidan vid effektbristsituationer. Elforsk report 05:31. http://www.marketdesign.se/images/uploads/2005/05_31.pdf
[72] http://www.reserveffekt.se/

a reduction of consumption because this standby generation replaces electricity that would have normally been transmitted via the grid.

Skellefteå Kraft's "Power Ladder" ("Kraftstegen" in Swedish) is an example of a peak load managing service. Skellefteå Kraft helps industrial consumers to maximize energy efficiency. In the last step of the Power Ladder, an overall judgement including peak loads is made[73].

Rotating interruptions is the option Sweden has chosen for situations of supply not meeting demand. Customers will be divided into "blocks" and disconnected for a couple of hours at a time. The project Styrel[74] has developed criteria for identifying and prioritizing customers that provide essential services to society in order to exempt them from the rotating interruptions. Load will be disconnected at transformer stations so all consumers connected to the same feeder will be disconnected. Some network companies with advanced two-way communications systems connecting their control centres and electricity meters at the customer's premises have the possibility to disconnect individual customers[75].

Fortum has three pumped storage facilities in Värmland and is planning to build a fourth (1.2 MW in Glava). These facilities are used when Fortum is bidding in balancing markets to reduce peak load. It is worth pointing out that pumped storage, as well as normal hydropower, tend to reduce price volatility in the spot market, especially in the south of the country. These facilities weaken therefore the incentives for small consumers to reduce their consumption.

Finally, coordinating wind and hydropower generation can reduce peak load. For example, Fortum operates a wind farm and a hydropower plant under the same load tariff contract. Output from the hydropower plant is reduced when output from the wind park is high so that the total load at the connection point remains reasonably constant. There are no automatic mechanisms to control output - hydropower output is controlled manually as the need arises.

4.2.3 Research and development in Sweden

The Market Design programme has sponsored four demand side management demonstration projects[76]:

- The electric heating load from 50 domestic customers connected to the grid of Jönköping Energi was reduced to 67 % of normal levels at five different occasions.
- A probe into the price sensitivity of domestic consumers connected to the grids of Vallentuna Energi and Skånska Energi.
- Remote control was used to reduce the load of a number of large industrial consumers by an average of 1 MW.

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[73] http://www.skekraft.se/default.aspx?di=1778

[74] http://www.energimyndigheten.se/styrel

[75] According to Pia Brühl-Hjorth, CEO Göteborg Energi Nät, at Swedenergy's regional meeting, October 8th, 2010

[76] Stefan Lindskoug, Demonstrationsprojekt - Effektstyrning på användarsidan vid effektbristsituationer. Elforsk report 05:31, October 2005.

- A survey to examine the potential for reducing consumption by controlling heat pumps.

One study assessed the impact of direct and indirect load control of electrically heated houses connected to the grid of Göteborg Energi during the winters 2007/2008 and 2008/2009. The directly controlled customers had water-based heating systems that could be switched off remotely by the grid operator when electricity prices were high. The indirectly controlled group had no automated control equipment but were put under a tariff with very high peak prices. These consumers were told that information about current spot prices would be available on a web site and were asked to manually adjust consumption in response to price changes. The study concluded that there is a potential for a more dynamic market, as some domestic customers are willing and able to defer their use of electricity in response to price signals.

There is ongoing research on demand response at the domestic level at Lund University[77]. The research group involved also participated in the demand response experiment described above.

Reducing peak loads could also become a goal of the planned demonstration projects that were mentioned in the previous section. However, many of the details of these projects are still unclear.

Skellefteå Kraft carried out a study into the feasibility of coordinating the output from wind and hydropower plants. The study was financed by the Vindforsk[78] programme. The project involved two hydroplants with a combined capacity of 24 MW and a planned wind farm with a capacity of 36 MW. Skellefteå Kraft came to the conclusion that it was indeed possible to coordinate the output from the different power plants, but that it results in an increased work load for personnel working at the control centre, and that it reduces the ability to optimize production levels.

4.2.4 Research and development in other countries

In Spain, the Transmission System Operator REE has a programme where large customers are paid for reducing their load when asked to. Participants must agree to load reductions of at least 5 MW, and there is a communications protocol that is used to verify that loads were indeed reduced.

In Finland, the Transmission System Operator Fingrid , uses disconnectable (interruptible) loads to maintain reserve. When the frequency falls below 49.9 Hz the frequency controlled disturbance reserve[79] will be activated. For this particular reserve, 542 MW are available as generation capacity (annually contracted or procured through an hourly market) and 40 MW as reduced consumption[80]. For

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[77] J. Abaravicius, Demand side activities for electric load reduction, Doctoral thesis, Lund, June 2007.
[78] Fredrik Öhrvall, Samkörning av vindkraft och vattenkraft i Skellefteälven Rebnis och Sädva vattenkraftstationer samt Uljabuouda vindkraftpark, Elforsk report 07:18.
[79] -
[80] http://www.fingrid.fi/portal/in_english/services/system_services/maintenance_of_frequency/

the manually activated fast disturbance reserve[81] 818 MW are available as generating capacity (gas turbines, both Fingrid's own installations and contracted outside) and 395 MW as disconnectable load. Load reductions are also used for capacity reserves in Norway, and at an experimental level in Denmark[82].

In an experiment carried out in the Olympic Peninsula in the northwestern part of the United States, a real time market was set up for small electricity consumers[83]. A village was fed via a cable that becomes overloaded on hot summer days. In the village, there were two gas turbines that could be started in order to reduce the load on the incoming cable, but the electricity produced by the two gas turbines was much more expensive than the electricity delivered via the incoming cable. In order to minimize the amount of time that the gas turbines were active a tariff where each consumer was allowed to specify the electricity price they were prepared to pay was introduced. The electricity price for the village as a whole was then determined in much the same way that the spot price is determined at the Nord Pool spot market. By using a simple market model and a simple communications solution it was possible to keep the load on the cable constant for a couple of hours.

In Canada, research has shown that given the correct price signals, it is possible to reduce peak load by as much as 20 %. If appropriate price signals are combined with the use of smart thermostats load can be reduced by as much as 50 %[84].

In the European project EU-DEEP a number of experiments were carried out to determine if the use of technologies such as demand response and microgeneration would be profitable for electricity consumers. An experiment carried out in England included: 30 MW wind power, 20 kW small offices, 150 kW local council offices, 250 kW and 1500 kW cold storage, 900 kW manufacturing industry, 1500 kW large offices, 50 kW hotels, 40 kW supermarket, and 20 kW small shops. The experiments showed that participation in demand response programmes could be profitable for electricity consumers. The outcome of the experiment was also fed into a set of simulations where the effects of different market models were taken into account. These simulations suggest that the effectiveness of demand response depends to a large degree on how electricity markets are structured[85].

OPTIGES is a Spanish project where Endesa and Tecnalia are examining the aggregated control of heating, ventilation, air-conditioning and lighting[86]. Customers are warned in advance that some of their load will be disconnected and have the possibility to override the action. A thermal model of a customer facility is used to forecast response, i.e. how much customer load will change given a certain

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[81] The fast disturbance reserve consists of active and reactive power reserves that can be activated manually within 15 minutes. After activating this reserve, the power system has been restored to such a state that it can withstand another potential disturbance.

[82] Enhancement of demand response, Final status report, Nordel demand response group, 18 April 2006.

[83] Rob Pratt, Scalable demand response networks: results and implications of the Olympic Peninsula GridWise demonstration, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.

[84] PowerCentsDC final report, September 2010.

[85] Gilles Bourgain, Franck Neel, The UK aggregation experiment combining wind and demand response, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.

[86] HVAC

change in temperature. Pilot tests that were carried out in 2009 showed that load reductions of up to 30 % are possible[87].

The GAD Active Demand Side Management Project is a collaborative effort with 27 partners led by Iberdrola from Spain and strongly supported by the Spanish government (23 million euros). The project's goal is to optimize the way electricity is used making consumers aware of the cost of generating electricity in real time, including the environmental costs. The GAD project focuses on the active control of domestic equipment (design of smart meters, control systems, design of communications networks and communication protocols, and operation of a complex system consisting of smart meters and smart appliances that can be remotely controlled). In the GAD project the smart meter will act as a gateway that will allow distribution or transmission grid operators to remotely control individual smart equipment located in the customers' homes[88].

Already mentioned in this report, the FENIX-project has received 14 million euro from the European Commission. FENIX's aim is to develop an infrastructure that facilitates the cost-effective integration of distributed energy resources. The project focuses on the supply side but will also examine how small consumers are affected by the increased use of distributed generation. Controllable loads being used as reserves are air conditioning and heating, thus ensuring availability both during summer and winter months. How consumers recover after a voluntary or forced load reduction is an area that the project will focus specifically on[89].

In Japan, a facility combining several local generation units and a number of loads has been constructed. The generation units involved are 330 kW solar power and seven fuel cells (25, 4 times 200, 270 and 300 kW), backed by 500 kW of battery storage. The demand side includes several office blocks and one water-cleaning facility. Both generation and demand are connected to the grid via one shared cable. While the maximum load in this microgrid is just over 1 000 kW, the load on the shared cable is usually held constant at about 100 kW[90].

PJM Interconnection, a regional transmission organization (RTO) that manages the high-voltage electric grid and the wholesale electricity market that serves 13 states and the District of Columbia, is at the forefront of demand response. Demand response is integrated into PJM Interconnection's wholesale electricity markets, providing equivalent treatment for generation and demand resources. Retail customers have the opportunity to participate in PJM's Energy, Capacity, Day-Ahead Scheduling Reserves, Synchronized Reserve and Regulation markets and receive payments for the demand reductions they make. Qualified PJM market participants who act as agents, called Curtailment Service Providers (CSPs), work with retail customers who wish to participate in demand response. CSPs aggregate the demand of retail customers, register that demand with PJM, submit the verification of demand reductions for payment by PJM and receive the payment

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[87] Iñigo Cobelo, Helping DER deployment through large-scale aggregation of controllable loads, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France.

[88] ibid.

[89] http://www.fenix-project.org/

[90] Asahiko Tokuoka, Large scale DER integration experiments in Japan, 3rd Int Conf on Integration of Renewable and Distributed Energy Resources, December 10-12, 2008, Nice, France

from PJM. The allocation of the payment from PJM to the CSP and the retail customer is a matter of private agreement between them[91].

Finally, several organizations are working to broaden the opportunities for demand response and looking into market designs to support demand response for domestic customers. The goal is to fully integrate demand response into the retail market. There are many ongoing demonstration projects in the United States, mostly funded by the U.S. Government. Most of the projects financed by the U.S. Department Of Energy (DOE) use electricity generation from renewable energy sources connected at low voltage levels as a way to reduce peak loads. Other projects examine demand response and energy storage. The Electric Power Research Institute (EPRI)[92] leads a number of demonstration projects that among other things examine the use of demand as secondary reserve[93].

4.3 Energy efficiency

4.3.1 Reducing electricity demand and network losses

There are many commercially available products that can be used to reduce technical network losses.

For instance, Gothenburg-based Vadsbo manufactures two models of distribution network transformers “standard” or “low-loss”. Losses in low-loss transformers are15-20 % lower than in standard transformers[94]. Västervik-based Hexaformer claims that its transformers result in "drastically reduced network loses"[95]. Other manufacturers such as ABB also sell transformers that reduce losses. According to a study conducted by Vattenfall Research and Development on behalf of Elforsk, total network losses in transformers in distribution networks in Sweden are 0.9 TWh fixed or iron losses and 0.4 TWh variable or copper losses. This amounts to 0.9 % of total consumption[96].

Although reducing network losses can increase energy efficiency, promoting energy efficiency on the demand side has received far more attention. There are energy efficient lighting products, electrical appliances, and home electronics products. Losses related to appliances’ standby mode have also received significant attention. The interest for energy efficiency has been boosted by information campaigns, energy efficiency labelling and rating of consumer products, and projects that have tried to provide consumers feedback on their

[91] http://www.pjmtech.net/
[92] Electric Power Research Institute, Palo Alto, California, US.
[93] http://www.smartgrid.epri.com/
[94] http://www.transformatorer.com
[95] http://www.hexaformer.se/. It are mostly iron losses that decrease, while copper losses remain almost the same as in a conventional transformer. Iron losses do not depend on current. Copper losses are proportional to the square of the current. The advantages of Hexaformer’s transformers are mostly felt under low load, which is most of the time, and which also is the case for most distribution transformers in Sweden.
[96] Fredrik Carlsson, Förluster i lokalnät, 26 May 2009. http://www.elforsk.se/distribut/elkvaldok/nummer%2010/bilaga_13.pdf

actual electricity consumption. The EU's Eco-design Directive[97] contains requirements that products and buildings become more energy efficient.

Energy efficiency measures for industrial facilities are of special interest since the potential savings are substantial. More efficient electric motors and alternative ways to design industrial processes are important contributions. More efficient electric motors would reduce electricity consumption between 2 and 6 %[98].

There are several ongoing efforts, both within and outside Sweden, to promote energy efficiency by reducing consumption. In Sweden, the Energy Authority is setting up an Energy Efficiency Advisory Council to coordinate efforts to promote energy efficiency in different sectors of society. At a European level, new European rules related to so-called passive houses[99] will come into effect 2018/2020.

The municipality of Skellefteå requires all companies it owns to reduce their energy consumption by the year 2016. The local energy conglomerate Skellefteå Kraft is coordinating this project, which has received the support of the Swedish Energy Authority.

4.3.2 Consumption feedback to consumers

Sweden was one of the first countries in the world to deploy automated meter reading on a large scale and has therefore been at the frontline in providing electricity customers with feedback on their own consumption. Since most network companies have installed meters that allow measuring all consumers hourly, the availability of consumption feedback is bound to increase. Some network companies have developed web-based portals where consumers can access information about their actual electricity consumption combined with advice on how to conserve energy. There are also more advanced web-based portals where consumers that are hourly measured can access detailed historical information about their electricity consumption. These portals also provide energy consumption simulation services where consumers are given advice on how to reduce their electricity consumption. For example, electricity consumption advice and electricity labelling are provided in the service called "Power Ladder" that was described in Section 4.2.1.

Both Vattenfall Research and Development and The Interactive Institute[100] participate in the European research project BeAware. The goal of this project is make customers aware of the existence of superfluous energy consumption. One of the sub-goals of the project is to determine to what extent smart meters can be used to make consumers aware of the potential to reduce energy consumption[101].

The University of Skövde has an area of research it calls Information Fusion. One of their projects looks at the automatic analysis of consumption information. Such

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97 EU's Directive 2005/32/EG establishing a framework for the setting of ecodesign requirements for energy-using products

98 Energy-efficient motor selection handbook, U.S. Dept of Energy, January 1993.

99 A "passive house" is a house with a very low energy use, with a cap of 120 kWh/m2/year in primary energy consumption for electricity, heating and warm [http://en.wikipedia.org/wiki/Passive_house]

100 http://www.tii.se/

101 http://www.energyawareness.eu/beaware/

automated processing can be used to detect typical consumption profiles with properties that are hard to detect using manual analysis. Consumption profiles bring to light differences in electricity use between different groups of customers and can be used as a base for automated energy advisory services.

The Interactive Institute participates in several projects that try to develop new products and services that will allow customers to play a more active role in the smart electricity system of the future. Earlier research by the Interactive Institute has shown that such products and services must be well-designed and fun to use if customers are to react to the information provided by changing the way that they consume energy.

4.3.3 Electrification of the transport sector

The electrification of the transport sector is one important component in the effort to increase energy efficiency. Currently the focus is on electric vehicles, but projects such as Stockholm Royal Seaport aim to show that the electrification of ports can also contribute to greater energy efficiency.

Research groups at Chalmers and Vattenfall Research and Development are examining how electricity networks will be affected by the large-scale introduction of electric vehicles that connect to the electricity network to charge batteries. Both groups have started projects that study methods to charge electric vehicles that minimize the impact on the grid. Chalmers also participates in Grid for Vehicles (G4V)[102] project, a European project that examines both impact and possibilities of the mass introduction of electric and plug-in hybrid vehicles on the electricity networks in Europe.

4.3.4 Energy efficiency in other countries

Experiments conducted by EPRI in North America show that it is possible to reduce network losses in most distribution networks by lowering the voltage. In an experiment, the voltage magnitudes for all consumers connected to a feeder were kept at the lowest possible. Active power was reduced by between 0.5 and 2.5 % when voltages are reduced by 1 %. In 33 out of 39 medium voltage feeders this led to a reduction of total energy (consumption plus losses) of 1 % or more. Only in two cases did the total energy increase. The average reduction was 1.5 %[103]. However, it is far from certain that the result would be the same in Sweden where electric heating accounts for a significant portion of the load.

4.4 Active consumers

Swedish retail customers can choose from a wide range of deals when purchasing electricity from an electricity supplier. For instance, consumers can select fixed pricing that freezes the price the customer pays per kWh for a certain period of time or consumers can choose to pay a variable price in which the kWh price varies each month according to the average wholesale market price. Several suppliers also offer green tariffs that reassure consumers that they are buying electricity that

[102] http://www.g4v.eu/

[103] K.R. Foster, Green circuits - Demonstration and a look at voltage optimization. EPRI PQ and Smart Distribution Conference, June 2010, Quebec City, Canada.

comes from a renewable source. However, Swedish customers have very little choice -if any- when it comes to the network tariff. The only way in which consumers can lower their network bill is by reducing consumption.

The Swedish authorities' requirement that domestic customers' electricity meters are read at least once every month, and that invoices are based on actual rather than estimated consumption, were introduced to make it easier for customers to play a more active role in the electricity market. The Inspectorate also developed a price comparison tool (Elpriskollen)[104] to enable consumers to compare electricity prices for suppliers in Sweden. It is currently the Inspectorate's most well-known activity. The web site has about 1500 unique visitors per day.

Also worth mentioning is Swedenergy's "Kundoffensiven", an industry initiative to increase customer satisfaction[105].

Many of the activities and initiatives described in the previous section will give customers the chance to play a more active role in the electricity market. Hourly metering has the greatest potential for increasing customer choice. It does not really matter if hourly metering becomes mandatory or if customers have to explicitly ask to be hourly metered. Several network companies that installed hourly meter reading for all customers are examining the introduction of novel network tariff structures. Suppliers could also benefit from hourly metering by developing new products, like for example dynamic rates that are based on wholesale prices.

4.5 Regulatory developments in other European countries

As part of the project described in this report, an international survey of smart metering and smart grid development in selected European countries (Denmark, France, Germany, Great Britain, Italy, Portugal, and Spain) has been carried out. The results are presented in Appendix B to the Swedish version of this report. The survey describes the different countries' approaches to transforming the electricity system, how Governments support the development and how authorities through regulation try to encourage companies to make the right decisions. Subjects covered are connection and integration of renewable generation, approaches to demand response, changes to tariff structures, use of smart metering systems, research &development, and plans for the introduction of electric vehicles. Several countries have also developed more detailed roadmaps to identify opportunities for smart grid implementation and barriers that could limit progress. The remainder of this section is devoted some of these developments.

4.5.1 Roadmaps

A roadmap represents a first step in identifying how electricity networks will change as a result of developments in smart grids, and in developing responses through which possible barriers can be overcome. Smart grid roadmaps are usually built up in similar ways and include four main steps.

104 http://www.ei.se/elpriskollen/
105 http://www.svenskenergi.se/sv/Aktuellt/Nyheter/Kundoffensiven2/

The first step of the roadmap focuses on the technical components that must be installed if smart grids are to become a reality. These components have to be developed, and standards that ensure that different components work well together must be agreed upon. This phase is characterized by concrete plans and intensive work around them.

Table 4.1 lists some countries that have created Smart Grid roadmaps.

	Year	Responsible Actor	Title
UK	2010	OFGEM	Electricity Networks Strategy Group, A Smart Grid Routemap
Germany	2010	VDE: Association for electrical, electronic and information technologies	The German road map – E-energy/ Smart grid
France	2010	Agency for Environment and Energy Management (ADEME)	Roadmap for smart grids and electricity systems integrating renewable energy sources.
Denmark	2010	Energinet.dk and Danskenergi	Smart Gris in Denmark
China	2010	State grid corporation of China	SGCC framework and road map for Strong & Smart Grid Standards
EU	2010	European Commission Enterprise and industry directorate-general	2010-2013 Action Plan for European Standardisation
EU	2010	ENTSOE, EDSO	The European Electricity Grid Initiative (EEGI) Roadmap 2010-18 and Detailed Implementation Plan 2010-12
EU	2010	ENTSO	Ten-year network development plan 2010-2020
International	2008	International Energy Agency	Empowering variable renewables – Options for flexible electricity systems
US	2008	Federal Energy Regulatory Commission	Assessment of Demand Response & Advanced Metering
US	2009	Gridwise alliance	Handbook for assessing smart grid projects.
US	2010	National Institute of Standards and Technology (NIST)	NIST framework and roadmap for smart grid interoperability standards, Release 1.0
International	2010	IEC	IEC smart grid standardization roadmap
Ireland	2009	Commission for Energy Regulation (CER)	CER Strategic Plan 2010 - 2014
California	2010	Southern California Edison	Smart grid strategy and roadmap
Australia	2010	Smart Grid Australia	Smart grid R&D – Roadmap for Australia

The remaining steps are more visionary. The second step focuses on demonstration projects. Equipment manufacturers and grid operators try to prove that their chosen solutions work. The third step describes financing for the fourth step, which is the actual massive deployment of smart grid technology. The roadmaps are generally very high level, and none of the road maps contain detailed plans for how a complete transition to smart grids is to take place.

Many roadmaps focus primarily on standardization issues. Standardization is seen as a prerequisite in order to create an environment where reliable and cost-effective supporting technologies are developed. In many cases standardization also aims to support local equipment manufacturers[106].

[106] Because the purpose of this overview is only informative and not evaluative purposes, no references have been given. It is meant to provide an overall view of initiatives started by October/November 2010.

4.5.2 Changes to regulation governing distribution grid operators

In all of the countries studied in the international survey, authorities use incentive regulation to stimulate investments in new grid technologies. No country has yet introduced detailed, binding technical requirements to speed up adoption of smart grid technology. Both France and the UK have established investment funds to stimulate the development and adoption of new technologies in the energy sector. In the UK, the "Low Carbon Networks Fund" was established to support large-scale trials of advanced technology sponsored by distribution network companies. The amounts available are 500 million British pound under 5 years. This translates into 3.4 pound per year per customer (27 million homes and 2 million non-domestic customers). Italy and Portugal both use incentive regulation mechanisms for electricity distributors under which network companies that invest in innovative technology are allowed higher rates of return for the particular installations.

In some countries network tariffs have been modified to make it easier to manage capacity shortages. France has had a TOU tariff with some elements of CPP - Critical Peak Pricing - for several years now, and there is continued strong interest in demand response schemes. French authorities want to make innovative tariffs available to all electricity consumers.

France has been exploring "distributed load shedding" for some years: a third party actor aggregates the load of many small customers into a single unit large enough to participate in the balancing mechanism. Loads (mostly electric heating) are remotely reduced when the aggregator submits an offer that is accepted by the balancing mechanism. Even Denmark, Spain, and the UK are exploring the opportunities presented by aggregating loads. In Italy, TOU tariffs are mandatory for all customers with smart meters that have chosen to remain on regulated electricity prices. Other countries have so far restricted themselves to voluntary TOU tariffs. The Spanish government has also pointed to the possibility of using electric vehicle batteries connected to the network as storage resources to compensate for the fluctuating output from renewable electricity production plants.

4.6 Conclusions

Sweden has come far in providing electricity customers with feedback on their own consumption and in encouraging customers to become more active in the electricity market. Crucial for this development was the metering reform and the large-scale deployment of smart meters that followed, one of the first in Europe. Sweden is also on the forefront in the adoption of technologies such as HVDC and FACTS that can be used to increase the transport capacity of transmission grids. These technologies will play an important role in the secure integration of electricity generation from renewable energy sources in Europe.

Sweden has also several mechanisms in place to reduce peak loads. Several grid operators offer TOU-based network tariffs; the majority also offer load tariffs to large consumers. Only two grid operators offer load tariffs to residential customers, although several grid operators show interest in extending load tariffs to smaller customers. Only a few suppliers offer TOU-based electricity prices, and no supplier offers dynamic rates that are based on wholesale prices. However, several electricity suppliers have indicated that they are interested in offering such tariffs once customers' consumption is measured hourly.

A number of demonstration projects are currently being planned in Sweden to investigate methods to integrate renewable generation to the electricity system. Sweden does not, however, have a leading position in this area. Other countries have carried out extensive research and demonstration projects in this area and have acquired technical know-how that Sweden lacks. Sweden also lags behind in research concerning the development of regulatory frameworks and market design. This is despite the fact that the Swedish electricity market is considered to be ahead in an international perspective.

5 Barriers and challenges

The previous chapter described past, current, and planned activities and initiatives related to smart grids in Sweden. To date, very few concrete implementation projects have been undertaken. This lack of progress can be explained by a number of factors that slow down progress in various ways. One important factor is that the technology is not yet sufficiently developed for large-scale adoption to take place.

This chapter describes factors that have so far acted as barriers to the development of smart grids in Sweden. It also presents key challenges for smart grid development that need to be considered and met. The conclusions that are drawn in this chapter are that while widespread adoption of smart grid technology faces many challenges, longer term most challenges will be removed or disappear.

Most of the material presented in this chapter is based on views and opinions presented by members of the external reference group, by relevant actors contacted by the Inspectorate, and by participants at a public hearing arranged by the Inspectorate. This has been complemented with publicly available information and the Inspectorate's own analysis.

The chapter is divided into five sections as the barriers and challenges identified fall under five headings: technical factors, financial factors, intangible factors, factors relating to smart metering, and factors related to customer engagement.

5.1 Technical barriers

Smart grid Technology is still in its infancy, and there is not yet an exact and widely agreed upon definition of what a smart grid is. The debate about how best to define a smart grid is mainly conducted at numerous international conferences where scientists, equipment manufacturers, network companies, various industry associations, and regulatory authorities meet. This means that it is currently very difficult to produce a requirement specification for a smart grid, which means that achieving the smart grid also becomes very challenging.

The technical challenges can be grouped as follows:

- Non-existing technology
- Seemingly redundant technology
- Lack of interoperability[107]
- Disadvantages of new technology
- Scepticism towards new technology

[107] Interoperability means that different devices and systems can cooperate and communicate with each other, even if they come from different manufacturers and have different ages.

5.1.1 Non-existing technology

It is widely accepted that the most significant technical barrier limiting the progress of smart grids is that all the necessary components are not yet commercially available. There is a lack of both individual components, and the supporting infrastructure to link these components to electricity networks so that the networks become "intelligent".

A first measure to identify the suitable components for smart grids is to standardize the various aspects of the smart grid. Countries such as China, Germany, and the US have launched comprehensive programmes to define standards for the components and subsystems that will make up the smart grid. Organizations such as the International Electrotechnical Commission (IEC) and the European Committee for Electrotechnical Standardization (CENELEC) are also working on smart grid standardisation issues.

At the same time numerous commercial firms are working on smart grid technologies. Some are large, well-established providers of energy and telecommunications systems such as ABB and Ericsson while others are high-skill start-ups that see business opportunities from the development of smart grids.

Product development and standardization efforts normally take a very long time. Standardization usually takes several years and attempts to speed up the process may result in inferior standards that can slow the adoption process rather than speeding it up. It therefore seems reasonable to conclude that lack of products and standards will be a barrier to smart grid development for the remainder of this decade.

5.1.2 Seemingly redundant technology

As long as electricity grids have sufficient transmission capacity to accommodate peak demand, network companies have no strong incentives to invest in new technology to smoothen peaks. Only when peak loads consistently approach the maximum transmission capacity does it become interesting for network companies to consider investments to handle peaks. It is first then that network companies will have to make a choice between traditional refurbishment and expansion, or investing in smarter technologies.

When it comes to the need to modify electric grids to handle large volumes of renewable generation, the situation is more complex. Many network companies and researchers claim that smart grid technology will be required to integrate even small volumes of renewable generation to the electricity system, but not everyone agrees[108]. However, everyone agrees that large networks investments will be required in order to integrate renewable generation to local distribution networks. What is lacking is a comprehensive vision of what the needs actually are and a plan to address those needs. The large-scale rollout of smart grid technology can therefore be said to be slowed down by two factors: not only are the necessary technologies far from market and in need of testing, there is also considerable

[108] Final report, EU-DEEP-project (http://www.eu-deep.com). The current electricity network is said in this final report to have a high hosting capacity.

uncertainty about which parts of the grid that must be upgraded, and when these investments must take place.

5.1.3 Lack of interoperability

Smart grid technologies are to a large extent based on geographically dispersed devices that communicate over one or more communications networks. The devices will be developed by different manufacturers and will emerge over time. It is therefore of paramount importance that there are standardized communication protocols that will allow a plethora of different devices to communicate with each other.

A lack of standardized communication protocols therefore represents a severe barrier to the widespread adoption of smart grid technologies. A considerable amount of standardization work is being carried out to remove this barrier. This has proved to be very challenging since there are so many competing IT communication standards. It may be difficult and time-consuming for the industry to agree on one standard.

A standard that has received considerable attention is IEC 61850, a communication standard for substation equipment that is being further developed to serve the smart grid.

Standardization work for smart grids is further complicated by the fact that there are two main strands of standardization work going on. On the one hand there is work to standardize communication protocols for devices that are located in electricity grids. There is also ongoing standardization work to standardize communication between control centres and smart appliances located at customer premises (where costs have to be kept low)[109]. These two strands have to be refined further but also merged somehow.

5.1.4 Disadvantages of new technology

Whenever a technical system is modified new weak spots may be introduced and the set of risks associated with the system changes. Even if the changes may not necessarily make the system more vulnerable to failure, the circumstances surrounding its use change as new risks and potential failure scenarios are introduced.

Even if the perceived risks of new technology do not constitute a barrier to implementation of the technology, uncertainty about the magnitude of the risks may limit progress. For instance, security threats related to equipment connected to the internet has received widespread attention[110], and since smart meters with capabilities for two-way communication communicate with central control centres in much the same way that web browsers on personal computers communicate with web servers it is not far-fetched to imagine a world where smart meters and the smart appliances that they control could be subject to attacks similar to those

[109] See the initiative IPSO User Sweden, att driva på utvecklingen med att skapa en standard för apparater och system i hem och fastigheter. Se http://www.ipsousersweden.se

[110] See for example, G.N. Ericsson, Cyber security and power system communication—essential parts of a smart grid infrastructure, IEEE Transactions on Power Delivery, Vol. 25, No. 3, July 2010, pp 1501 - 1507.

directed against personal computers. The two-way functionality in many smart metering systems can be used to remotely control appliances at the premises of electricity consumers, and if security in the smart metering communications network was breached somehow, the consequences could be severe. Regardless of how severe the threat actually is, the mere fact that it is being widely discussed means that network companies will be asked to equip their smart metering systems with technology to safeguard the system against attacks, and to provide guarantees to consumers that attacks will not be successful. Especially the latter could form a barrier to the adoption of smart grid and smart metering technologies since many network companies might come to the conclusion that it will be too expensive to provide the level of security that consumers ask for.

Smart grids will be considerably more complex than traditional grids. This increased complexity places higher demands on the reliability of individual components as well as on redundancies in the systems as a whole (concerning manoeuvrability and control).

The biggest problem in computing the reliability of a complex system is the difficulty to estimate the likelihood of so called common-mode errors. These are situations where one underlying error causes the failure of several distinct components, or that a failure of one component leads to the failure of other components. One classic example of this phenomenon is the fire in 2001 in a cable in Akalla outside Stockholm. In this incident the reserve cable had been placed in the same tunnel as the main cable. This led to a situation where an underlying fault caused both cables to fail at the same time. In complex systems the number of fault combinations are so numerous that it becomes more or less impossible to rule out the occurrence of such situations.

Increased complexity tends to magnify the consequences of faults. If no measures are taken to reduce risks, the combination of increased threats, risks and weaknesses leads to a situation where the system becomes more vulnerable to failure. Even if large-scale disruptions do not become more frequent, their consequences may be more severe and difficult to handle.

It should be noted however, that the transmission grid, which currently is the most complex part of the overall electricity grid, actually combines high reliability and complexity for example in the form of SCADA[111].

It is important to pay close attention to the potential reliability problems of the new communications networks developed for smart grids, but the problems will most likely be solved in the end. The same is true of problems related to security of smart metering systems. Currently the problems faced by smart grids and smart meters are not more serious than problems previously faced by other technologies when they were new. But if these problems are not solved, they will seriously limit the progress of smart grids.

[111] SCADA: ”supervisory control and data acquisition”; a system for the operation, control and monitoring of electricity networks and other large installations.

5.1.5 Scepticism towards new technology

Smart grid technologies are new and untested and are therefore surrounded by considerable uncertainty. It is therefore not surprising that the technology is met with some scepticism from many stakeholders. To some extent such scepticism should be regarded as healthy, especially since the electricity sector provides an essential service to society. However, scepticism that degenerates into an instinctive rejection of everything that is new cannot be regarded as healthy.

Swedish network companies have realized that the transition to smart grids will be just as challenging as the introduction of automated meter reading. Experiences from that deployment show that there are real risks for technical fragmentation when network companies are forced to select from a set of alternatives with varying degrees of maturity. Early decisions need to be the right ones. If the smart grid deoployment is started too quickly, before it is even clear what the smart grid is supposed to achieve, network companies run the risk of selecting technical solutions that that do not solve long-term problems. If this were to happen, network companies may have to replace their initial solutions with better alternatives, at great cost.

In a market economy, the state cannot step in and select the technical solutions that independent actors such as network companies should adopt. However, the state can support research and development activities in a way that disseminates knowledge about the technology to all stakeholders. Such knowledge dissemination could contribute to an environment where network companies have the information they need to make informed investment decisions.

5.2 Economic and financial barriers

Once the technical barriers have been removed, the speed at which smart grids are implemented will be determined by how valuable the services provided by smart grids are to electricity consumers and society at large. There are therefore a number of potential economic and financial barriers to the adoption of smart grid technologies. These obstacles can be grouped as follows:

- Investment barriers
- Uncertain long-term profitability
- Uncertain revenues

5.2.1 Investment barriers

Network companies have pointed out that while the potential benefits delivered by smart grids will accrue to suppliers, customers and society as a whole, the costs will be borne entirely by the network companies. This financial imbalance is seen as a barrier.

Smart grid technologies require at present greater capital investment than conventional technologies. Smart grid technology is relatively new. Many components are still far from mass market and are only manufactured in small series, making them more expensive. This means that a smart grid investment that has a long-term value in that it represents a step in the right direction may be more expensive than a conventional alternative as a means to solve a particular short-term problem. Also, the deployment of new components brings up concerns over stranded asset costs. It is not obvious that it makes financial sense to replace conventional technology that has not yet reached the end of its life cycle with smart grid components.

These barriers may slow initial investments towards a smarter grid. This will be a problem for equipment manufacturers that will find it difficult find a market for their products.

5.2.2 Uncertain long-term profitability

Smart grids may prove integral to the transition to an environmentally sustainable society and will likely deliver benefits for network companies, network customers, and society at large. Society will benefit because smart grids will make the integration of large amounts of low carbon generation possible. Customers will be able to save money on their electricity bills. Smart grids enable them to lower their total energy consumption, though not necessarily their electricity consumption. It will for example become possible to choose electric cars. There is a general consensus that smart grids are a cheaper alternative to conventional grid reinforcements to integrate low carbon generation.

For network companies, smart grids could lead to a lesser need for capital investments in the long term. While this may at first seem like a benefit, it is not necessarily a financial benefit for the network companies. Because electricity networks are natural monopolies, the companies running the networks operate within a regulatory framework and returns on investment are regulated. Network companies' level of return is determined by considering the initial purchase value of the company's fixed assets. This means that reducing investments will reduce revenue. Furthermore, there is uncertainty regarding exactly what type of investment, under the regulatory framework, should be considered as network operation.

Network companies are obliged by law to develop their grids for the benefit of society. The opportunities offered by smarter grids cannot always be matched by conventional technology. Networks can be reinforced and expanded, but it takes a lot of time. It could therefore be argued that smart grids will make it easier for network companies to fulfil their obligations to society.

The advantages of smart grids are based on comparisons between the expected performance of smart grid technologies and the actual performance of existing technologies. The reason that expected and actual performances are compared is that smart grids do not exist yet. If the actual performance of smart grids was to diverge significantly from the expected performance, the profitability of smart grid investments may turn out to be very different than expected.

A number of measures need to be taken in order to reduce these uncertainties and create an environment where network companies will be able to determine if the actual performance of smart grid technologies will be in line with current (very high) expectations. Smart grid components will have to be developed further, demonstration projects will have to be carried out, and mechanisms to make knowledge about the actual performance of smart grid technologies available to network companies will have to be put in place. A stable regulatory environment will also be required to reduce the uncertainties faced by network companies.

5.2.3 Uncertain revenues

Because electricity networks are natural monopolies, network companies are not subject to competition and their returns are regulated. The new network regulatory framework that will come into effect in 2012 allows returns on investments as long as these investments are necessary to support the core activities of distribution companies - electricity distribution and metering.

The new regulation allows network companies to invest in new technology. However, it lacks clear incentives to encourage network companies to invest in smarter grids. The clearest barrier is that because smart grid technologies are relatively immature, network companies may be naturally inclined to prefer traditional, proven solutions. Special incentives may be required to overcome this.

The new regulation is designed to give network companies a lot of freedom when making investment decisions. It does not represent a barrier to smart grid adoption. There might be a number of perceived obstacles, but these should disappear as network companies become more familiar with it. However, some kind of investments may require special financing, but these will be handled by special regulation.

5.3 Intangible barriers

In addition to the technical and financial barriers to smart grid adoption, there is also a set of challenges that can be described as intangible. These fall under three headings:

- Lack of knowledge
- Regulation
- Absence of central actors that are responsible for the grid transformation

5.3.1 Lack of knowledge

The vision of the smart grid is currently just that - a vision.

Market participants have little understanding of what the requirements on electricity networks will be in the future, and how smart grid technology can be used to meet these requirements. In many cases network companies do not yet know how new circumstances, such as the widespread penetration of renewable distributed generation in distribution networks, will affect electricity networks and how networks must be adapted for these new circumstances. Furthermore, network companies often have very limited knowledge on the behaviour of renewable electricity production technologies and how these affect electricity grids.

Widespread specialization has led to a situation in which engineers often possess very detailed knowledge of individual grid components or small sections of the electricity network. Few individuals possess broader knowledge that allows them to see "the big picture" and the potential benefits of smart grid technology.

A general knowledge deficit in the electricity sector is therefore a barrier to the adoption of smart grid technology. This barrier can only be removed through educational campaigns and information dissemination campaigns. Finally, smart grid adoption might be slowed down by a general deficit of trained staff in the industry.

5.3.2 Regulation

Regulatory frameworks tend to be based on circumstances of the past with the first and foremost aim to regulate the present.. Such frameworks are usually not well adapted to rapid change and for circumstances that could not have been anticipated when the rules were written. This is true for all regulatory frameworks including those that govern the electricity sector in general, and the activities of network companies in particular. The existing set of rules that govern the activities of network companies can therefore, to a certain extent, act as a barrier to the widespread adoption of smart grids.

Grid infrastructure authorisation procedures can slow down and hinder the adoption of smart grid technology.

Smart grid adoption might also be slowed because the set of roles described in current regulatory frameworks do not include some of the roles that may be required in an electricity market based on smart grid technology. When the electricity market was initially deregulated, it was divided into two different parts - a deregulated market where electricity is bought and sold, and a regulated market for transmission and distribution. If smart grids are adopted, new actors and market functions may emerge, and it might be difficult to assign these actors to the roles described in current regulation. The new actors may be subject to regulation pertaining to several traditional roles and this may slow down adoption of smart grid technology. Battery storage at low voltage levels is a case in point. Battery storage can be used to limit excess voltage levels and excess currents in low voltage grids. Seen like this, operating battery storage is a kind of grid operation and should be regulated like any other network company activity. However, battery storage can also be viewed as a generating resource. The owner of the battery storage can use it to bid in spot markets and balancing markets, something that network companies are not allowed under the existing regulation.

The regulatory framework is being continuously modified to either remove such barriers or to minimize their effect on the adoption of smart grid technology.

5.3.3 Absence of central actors that are responsible for the grid transformation

The transition from a conventional grid to a smart grid will require substantial investments in both development work and physical installations. If network companies are to make the necessary investments, they will need long-term stability and an ability to predict what the pay-off from investments will be with reasonable accuracy.

Even if these conditions are fulfilled, there is currently no actor with the overall responsibility of delivering a smarter grid and ensuring that the transition to a sustainable energy system happens in a cost-effective way. This can be viewed as a barrier to the adoption of smart grid technology since there is no actor that is in a position to evaluate the consequences for the electricity system as a whole on various investment decisions. The fact that different actors are responsible for the transmission grid, regional grids, and local distribution grids can also be a considered a barrier.

5.4 Barriers to customer engagement

Support for customer engagement is a core component in many of the visions for the smart grid. Consumers reacting to price signals that reflect the overall pressures on the system is a vital aspect of smart grids. The rate at which smart grids are adopted will depend on how realistic visions of customer engagement are. Smart grids may still be built even if it turns out that the customer engagement does not materialize, but it will become more difficult to realize some of the benefits described in this report: reduce load peaks, facilitate the large-scale integration of renewable generation and increase energy efficiency.

Creating an environment where electricity customers can and will be more active faces a number of barriers that can be grouped as follows:

- Barriers due to lack of information
- Financial barriers

5.4.1 Barriers due to lack of information

Transparency is an important property of any well-functioning market. Market participants need access to correct information in order to act in the market. This is true of any market, and the electricity market is no exception. Customers today face an environment where there are many different market places for different products and services that they can participate in. It is reasonable to expect that customers will focus on those markets where the benefit from participating is in line with the effort to participate - that is in markets where there is choice.

Most electricity customers are currently not aware of the potential benefits of hourly metering. Experience from network companies that have tried to inform customers about hourly metering shows that concepts needs to be further developed further if domestic customers are to participate in the electricity market in a meaningful way.

5.4.2 Financial barriers

Financial incentives can make customers more active in the electricity market, and the larger the incentives, the greater the probability that customers will become more active.

Most electricity suppliers currently offer contracts where prices are fixed for long periods. These give customers predictable monthly costs and reduce the risk of high electricity bills following periods of price spikes in the spot market. Some electricity suppliers also offer a so-called balance account that gives consumers a fixed monthly cost. Such contracts may represent a barrier to customers reacting to price signals.

Domestic customers can also select variable price contracts, but variable actually means that the price changes once every month. Customers can influence costs by reducing overall consumption, but they do not make any gains by shifting load from peak to off-peak hours.

There are currently no network tariffs that encourage customers to shift load away from periods when the grid is under strain. Network tariffs usually have a fixed part and a minor part based on consumption so any reduction in consumption will have little effect on the total bill.

To give customers the ability to participate in the electricity market, their consumption must be measured on an hourly basis. Furthermore, contract types for both electricity and network access will have to be modified so that customers are given strong incentives to shift demand from peak to off-peak periods.

5.5 Barriers to smart metering

Smart metering is fundamental if the vision of the smart grid includes the active participation of domestic customers in the electricity market. It is possible to build smart grids without smart metering, but the potential of the smart grid would be restricted. Therefore, barriers to smart metering are also barriers to smart grids.

Measuring electricity consumption is a relatively straightforward process, but various factors can result in uncertainties over the quality of the measurements obtained. These uncertainties can be regarded as barriers to smart metering. Historically, there has only been a need to measure energy flows in one direction. At points where flows in both directions are likely, two meters, one per direction, have usually been installed.

Problems arise when consumers that have only one electricity meter both generate and consume electricity. Some meters count net generation as zero consumption[112], while others register net generation as consumption with the same absolute value. If a customer generates in one phase and consumes in another, different meters give completely different results. One of the goals of the Net Metering Project[113] is to find a standardized solution for this problem.

When other values, such as reactive power or customer contribution to ancillary services, are measured, there are additional methods to compute values from sampled values of currents and voltages. As long as these kinds of uncertainties remain, and as long as there is no standard solution, adoption of smart metering will be slowed down.

Before equipment manufacturers can sell new metering products these have to be tested and certified, and this is usually a very time-consuming process. To completely replace existing meters with new smart meters would take several years. Almost inevitably, the first meters that are replaced in a multi-year

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112 i.e. when a customer's total consumption is larger than his total generation during, for example, one hour.

113 Nettodebitering - Förslag till nya regler för användare med egen elproduktion, the InspectorateR2010:23

deployment will be obsolete by the time the last meters are installed. This is what happened in Sweden during the massive replacement program that was launched to implement the monthly metering reform. The network companies that were last to install meters today have the most advanced meters (often with two-way communication and hourly-metering capabilities).

The fact that meters are of interest to customers, electricity suppliers, and network companies alike is a challenge in itself. It is not obvious who should make the investment, who decides what functionality meters should have, who should have access to meter values, and so on. Furthermore, functions such as direct control of smart appliances and real time dissemination of electricity price can be implemented using various existing technologies and do not have to be part of the actual meter.

5.6 Summary

Widespread adoption of smart grid technology is slowed down by the existence of a number of technical problems that have not been solved yet. Such a situation is normal whenever new technologies are introduced. Many countries have launched significant smart grid research and development programmes funded by both government and the private sector. There are also a number of standardization efforts underway. While standardization is often valuable, it is important that standards are not rushed through too quickly. Bad standards can become barriers to development rather than facilitators of development. It is up to the participants in the market for new products to develop the necessary standards. The role of the state is to support research and development activities that stimulate knowledge dissemination so that Swedish industry is given opportunities to participate in the development of smart grid technologies.

Since network companies face stringent security of supply and quality of service requirements, it is natural that they are sceptical to potentially disruptive new technologies. This sceptical attitude to new technology is to some extent a barrier to the adoption of smart grid technologies. It is therefore important that knowledge about the benefits of the new technology reaches as many network companies as possible. Convincing a sufficient number of network companies of the benefits of smart grids will probably involve a number of demonstration projects. However, it is important to note that demonstration projects that are given the wrong focus, or that are carried out under the wrong circumstances, can actually lead to increased scepticism.

Technology shifts usually require substantial investment. This is true for all fields, and electricity networks are no exception. However, network companies run local monopolies and are heavily regulated, so competition is not the driving force behind the need to invest. Instead, it is the regulatory framework that governs the activities of network companies and that partly set the climate for investments. Questions about the scope of investments and investment incentives are analysed in Section 6.1 and 6.2.

The electricity network sector suffers from a lack of skilled personnel in general and people with knowledge about the overall properties of the entire grid in particular. This deficit has left many technical problems relating to smart grid adoption unsolved. It has also led to a situation where most network companies are fairly sceptical about the advantages of smart grids. The skill deficit issue is discussed in detail in Section 6.6.

The current regulatory framework might be perceived as an obstacle to smart grid adoption by some actors. The Inspectorate's view is that the regulatory framework does not represent a serious obstacle to smart grid adoption. However, there are three areas where further study is required. Firstly, the boundaries between regulated network activities and unregulated activities must be clarified. These boundaries are important because they affect how certain smart grid investments are financed. Secondly, the structure of network tariffs may need rethinking. Finally, the fact that no overall strategy has been formulated for reaching various energy policy targets (transforming the energy system into a sustainable energy system, widespread use of renewable electricity production facilities) may affect the adoption of smart grid technologies. These issues are discussed in detail in Section 6.3, 6.4, and 6.5.

Electricity customers must become active participants in electricity markets if the smart grid is to reach its full potential, and active electricity customers require smart metering. Smart metering adoption faces various barriers. One important obstacle is the lack of standardized solutions for handling customers that act as both consumers and producers of electricity. Furthermore, uncertainties remain about issues like the ownership of meters and access to metering data. Issues related to smart metering are analysed in detail in Chapter 7.

6 Analysis and considerations

In the previous chapter, a number of barriers that explain why smart grids have not yet been deployed on a large scale in Sweden were described. Also described were other factors that have the potential to limit the progress of smart grids. It was also argued that smart grid adoption faces many challenges, but that most of these will probably be overcome over time.

The previous chapter also identified a number of problem areas that will require further analysis. This analysis will be presented in this chapter. The problem areas that are discussed in this chapter are:

- How the rules that govern network company revenues affect network investments and the way they are financed
- Incentives for smart grid investments
- The boundaries between regulated grid activities and non-regulated activities and how these boundaries may have to be modified to accommodate smart grids
- How network tariffs should be modified to stimulate active consumers
- Problems associated with the general lack of knowledge about smart metering
- The need for a national action plan for smart grid deployment

6.1 Financing grid investments

The existing electricity grid was mostly built during the 50s, 60s and 70s in response to a rapidly growing demand for electricity at the time. Especially local and regional networks date back to these decades. Large investments will have to be made in the grid in the future - either to modernize grids using smart grid technologies, or to replace ageing components.

When network companies consider future investments they will have a choice between new or conventional technology. Electricity networks are complex systems with stringent requirements on reliability and a long-term view. The impact of any investment decision will be felt for decades to come, so the choice between new and conventional technology is not always an easy one.

The electricity network businesses are natural monopolies so their revenues are regulated. By law, the network companies are entitled to set tariffs so that they receive fair returns on the investments they make provided these investments are appropriate. The choice between smart grid and conventional technology can therefore be affected by the rules that govern how network companies set tariffs. Starting in 2012, Swedish network companies will be subject to a new regulatory framework where allowed revenue of network companies is set ex ante. This section contains an analysis of how smart grid adoption is affected by the new regulatory regime[114].

6.1.1 Tariff regulation and its impact on investments in new technology

The new ex ante regulatory framework means that network companies will be regulated through four-year price control periods starting in 2012. Network companies are obliged to in advance provide the Inspectorate with a proposal for their revenue allowance - what they think they should be able to earn from consumers. Revenue allowance proposals are based on the company's existing assets including planned investments and reasonable operating costs. Instructions on how to write such proposals and information on how proposals are evaluated is found in document EIFS 2010:6[115]. The allowed revenues are determined by computing depreciation and interest on the asset base, and by considering reasonable network operating costs.

Facilities that are included in the asset base

Network assets that are required for the operation of the network are part of the asset base. It is important to note that the facilities must be used for operating the grid (Regulation (2010:304) fixing allowed revenue under the Electricity Law (1997:857), 3 §) if they are to be included in the asset base. This means that new and advanced components, such as those found in smart grids, must be used to transport electricity, or to support the operation of the grid in some way, if they are to be included in the asset base. Components must not be owned to be included. Components that are leased or rented may also be included, provided the network company has full control over their use and that they are used for the operation of the network.

All components of the asset base must fall under one of three categories:

1 Lines
2 Station, transformer, or auxiliary equipment
3 Systems for monitoring facilities used to transport electricity, or systems for measuring consumption and injection of electricity, for managing measurement data, and for reporting measurements.

In EIFS 2010:6 the three categories are described as follows:
Category 1 includes all overhead lines, underground cables, signal cables, and sea cables that belong to regional or local networks. This category also includes closely related equipment such as poles, towers, cable boxes, and switchgear.

Category 2 includes primary and secondary substations, transformers and receiving and distribution stations.

Category 3 includes electricity meters and control equipment. Operations and monitoring systems could be anything from a computer system devoted to monitoring one or more assets, to a centrally located computer system that is used to process measurement data from electricity meters. Examples of meters are

[114] In this context, tariff regulation means assessing whether a concession holder's revenue from network operations are reasonable and justifiable, according to the Electricity Law, chapter 5.
[115] EIFS 2010:6, Energimarknadsinspektionens föreskrifter och allmänna råd om nätkoncessionshavares förslag till intäktsram och insamling av uppgifter för att bestämma intäktsramens storlek

single-tariff meters, TOU meters, load-tariff meters for low voltages, and load-tariff meters for either low or high voltages that measure both active and reactive power. Examples of IT systems that are included in the category are SCADA systems for controlling and monitoring the grid, software systems to collect and process measurement values, and software to make processed measurement data available to eligible actors. The latter includes software that may transmit processed measurement data over communication networks to remote actors.

The value of the asset base

A present purchasing value must be computed for every asset in the regulated asset base. This should be done using one of the following methods:

- **Normative value** (present purchasing value is determined by a normative price list that the Inspectorate has compiled)
- **Purchasing value** (if special conditions apply the present value can be set to the purchasing value adjusted for price inflation)
- **Book value (**for older facilities for which there is no information on purchasing value, the book value can be used instead)
- **Justifiable value (**can be used if there is no book value, or if very special circumstances apply)

The most common method to price the asset base will be the one based on normative value.

Smart grid investment will most likely involve components that are not included in the normative price list that the Inspectorate has compiled. Unless a smart grid component is very similar to a component already on the list, it has been proposed that the purchasing value is used to price the component when computing its contribution to the value of the asset base. The Inspectorate believes that most smart grid components will fall under categories 2 or 3. This means that the regulation is not a barrier to smart grid investments even though many smart grid components will not be present in the normative price list.

Cost of capital

The asset base is used to calculate the cost of capital that will be used for setting the allowed return for the price control period. The cost of capital is split into depreciation and interest though a real annuity where the value of the asset base is increased by an inflationary factor based on the construction cost index determined by SCB.

Economic life time of the asset base

The Inspectorate does not have the right to specify what the depreciation period should be for the installations that are included in the asset base. However, the Inspectorate publishes what it believes is a reasonable average expected economic life of the asset base for the three categories of equipment:

40 years	Category 1 (Lines)
40 years	Category 2 (Stations, transformers, auxiliary equipment)
10 years	Category 3 (control and monitoring systems, systems to collect and process meter readings)

When network companies hand in their allowed revenue proposal to the Inspectorate, they may argue for depreciation periods that are different from those specified above. The length of the depreciation period for an investment is expected to be an important factor when network companies choose between conventional solutions and smart grid solutions. Smart grid solutions are to a large degree based on components such as software systems that have shorter depreciation periods than components that are part of conventional solutions. Appendix A to this report lists expected depreciation periods for various smart grid components. In two of the smart grid cost-benefit analyses that are described in the appendix with this report the depreciation period used was 20 years. This must be considered a barrier to smart grid adoption since the depreciation period for conventional solutions is 40 years. The appendix also describes a number of cost-benefit analyses for smart metering projects. It turns out that 10 years is a normal depreciation period for such projects. This is in agreement with the 10-year depreciation period for category 3 equipment which is natural since most smart metering equipment falls into this category.

The three categories of asset base components were created without the technology mix of smart metering in mind. As smart metering technology matures and new products enter the market the Inspectorate will continuously evaluate the set of suitable depreciation periods for both old and new components coming into the market. Longer term, this might lead to the creation of new component categories. The Inspectorate therefore feels that the present regulatory framework does not represent a barrier to smart grid adoption.

Discount rate

The Inspectorate does not have the right to specify the discount rate. However, the Inspectorate will set an interest rate based on the Weighted Average Cost of Capital (WACC) every year. The WACC is the parameter that has the largest effect on the allowed revenues of network companies. The parameter is supposed to reflect reasonable return on investments given the risks inherent to grid operations. According to the rules all facilities that are required for network operations are given the same return on investment regardless of differences in risk between different facility categories. The WACC is determined based on the risk level faced by the electricity grid sector in general. Theoretically this means that network companies are given allowed revenues that reflect actual risks. However, network companies may ask for different returns on investments for some of their facilities when they apply for revenue allowances.

6.1.2 Incentives that encourage and/or discourage investments in smart grids

Network companies have so far indicated that they believe that investments in smart grids will be too expensive. However, smart grid investments need not be more expensive than conventional investments if smart grid investments have the effect that conventional investments can be avoided and if the networks can be operated more efficiently using smart grid technology. Furthermore, investment in conventional solutions could also prove to be very expensive in the long run if they carry with them higher operational and maintenance costs, or if some investments have to be brought forward in time.

Within the IMPOGRES research project, financed by the EU[116], a number of cost-benefit analyses have been done where conventional solutions (business as usual) were compared to smart grid solutions (active network management). Comparisons involved different types of distribution networks with different amounts of renewable generation. According to the study, smart grid solutions were on average 5-10 % cheaper than conventional solutions. Depending on the type of grid and on the amount of renewable electricity generation connected to the grid, savings ranged from 1-2 % to approximately 40 %.

Nevertheless, detailed assessments of the longer-term potential costs and benefits of smart grids are still missing. Cost-benefits analyses can therefore be an important support to decision-making especially because external benefits (e.g. environmental) can be considered. The construction of a knowledge platform including costs and benefits of smart grids should therefore be given priority.

Below is a summary of the factors that work for and against smart grid adoption.

The following incentives are expected to speed up smart grid adoption:

- If an installation is used for network operations then it should be part of the regulated asset base.
- Longer term, there is the possibility of adjusting depreciation periods and cost of capital.
- All components of a smart grid that are used for network operation become part of the asset base
- Network companies are informed in advance if investments that are not replacement investments may be added to the asset base
- New rules have been added to the Electricity Law (chapter 4 11-13 §) requiring network operators to provide new producers wishing to be connected to the grid with timetables for processing requests and for grid connection, as well as rules for sharing the costs of connection.

The following factors are expected to act as barriers to smart grid adoption:

- A new and untested regulatory framework creates uncertainties about what kind of installations that can be added to the asset base
- Court proceedings may be required to decide the exact returns on investment and depreciation periods that should be applied when revenue limits are set
- When investments fail (e.g. when the useful (physical) life of an investment is shorter than the regulatory depreciation period) the risks are carried entirely by the network companies or their customers
- The new regulatory framework values all assets to their present purchasing costs regardless of their actual age and this may result in a weak incentive to invest.

Of these four potential obstacles, it is the last factor that poses the biggest threat to smart grid adoption. Since the network companies are compensated for assets regardless of age, it might give network companies incentives to avoid investments

[116] Improvement of the Social Optimal Outcome of Market Integration of DG/RES in European Electricity Markets, www.improgres.org

and instead increase dividend payments to owners. Such tendencies can be countered by various kinds of quality incentives. The new regulatory framework allows network companies that improve reliability and quality of service to raise prices. To stimulate smart grid adoption, products and services that require smart grid technology can be given preferential treatment so that network companies that provide these products and services are allowed to raise prices. Such a solution is discussed in detail in Section 6.2.

Basic obligations of network companies (i.e. concession holders)

The Electricity Law states that network companies have a number of basic obligations. From chapter 3, 1 § in the Electricity Law: *"A network company is responsible for operating and maintaining its electricity network. It is also responsible for expanding and reinforcing its network and connecting its network to other networks when the need arises. The company is also responsible for ensuring that its network is safe, reliable, and that longer term, the network will be able to handle all reasonable demands on transport of electricity."* This should be interpreted to mean that network companies are obliged to take measures that guarantee that their electricity networks will be able to function well not only today, but also in the future. This should be an incentive for network companies to choose new solutions over old solutions whenever the new solutions are better (safer, more reliable, more efficient, etc.). Given guarantees of reasonable returns on investments, network companies are therefore obliged to take measures that guarantee that they will be able to connect electricity generation from renewable energy sources, provide high quality services to their consumers, live up to the other requirements in the Electricity Law, and follow the rules and directives issued by the relevant authorities.

The new regulatory framework should give the network companies the financial manoeuvrability they need to fulfil the requirements in the electricity law and to fulfil their obligations to society and to their customers.

6.1.3 Research, development and demonstration projects

Several network companies regard uncertainties over the financing of demonstration projects as a barrier to smart grid adoption. There is an ongoing debate over how demonstration projects should be financed, both in Sweden and in the rest of Europe. This section discusses financing options for research, development and demonstration projects in Sweden.

It is not obvious that regulated monopolies should engage in research and development activities. The Swedish Competition Authority has recently tightened the rules that govern how organizations controlled by municipalities or by the state can act on competitive markets. It is not obvious that research and development should be considered core network company activities, and there are risks for cross-subsidies and inappropriate competition if regulated monopolies compete for research grants on an otherwise competitive research and development market.

The regulatory framework that governs network companies does not contain any explicit allowances for research and development activities. Network companies are of course allowed to spend part of their revenues on research and development. The need for research and development and the corresponding risks are taken into account when the WACC is computed. This could be interpreted to mean that network companies do have some room for research and development.

Costs related to research and development are usually treated as direct costs, or can be added to the balance sheet if it is more or less certain that they will lead to revenues in the future. Most likely only a few network companies carry out research and development on a larger scale. Such research is usually funded by the parent company or through various state grants.

Demonstration installations

Demonstration installations are not explicitly mentioned in the new ex ante regulation. There are currently a number of demonstration projects being planned, including Stockholm Royal Sea Port ("Norra Djurgårdsstaden") in Stockholm, Västra Hamnen in Malmö, and the Gotland Smart Grid project. The purpose of each project is to build isolated, but fully functional smart subgrids. Some of these projects have received funding from the Swedish Energy Authority. If these demonstration projects are successful and the network companies decide to operate the installations as part of their main business, the new regulatory framework allows these installations to become part of the asset base. This means that demonstration installations that go on to become a part of normal network operations can become regular assets and can be included in the regular asset base used to calculate a network company's allowed revenue.

The level of risk associated with demonstration projects is usually higher than for normal investments. There is uncertainty about whether benefits will be delivered, the useful life of components may turn out to be shorter than the assumed economical life, or further investments may be required in the future. Some of these risks will be borne by the network companies themselves, while other risks will be transferred to their customers. It is difficult to predict where the main risks lie, as is normal when new and emerging technologies are developed and tested. Risks related to investments in conventional technologies are not non-existent either. One of the purposes of demonstration projects is to identify these risks and to make sure that the risks are reduced when the technology is used on a larger scale in the future.

Therefore, it is deemed reasonable that large-scale demonstration projects that carry higher risks and uncertainties than normal investments should not be financed exclusively within the ordinary regulatory framework, but rather via special funding mechanisms. It also seems reasonable that the results of these large-scale projects are made available to as many actors as possible. In order to reduce the risks of large-scale demonstration projects it is important that all results from similar research efforts are evaluated before the project is launched. It is then up to the company to decide how much risk it is prepared to take. Finally, the Inspectorate should have the right to reject demonstration project proposals if it believes that the proposed project does not contribute to the delivery of a sustainable energy sector.

6.1.4 Options for financing smart grid investments and their associated risks

Regulated monopolies and companies that act on competitive markets have different approaches to risk and financing with investments decisions. Companies exposed to competitive market forces can justify the risks associated with an investment in that the investment can enable them to develop products and services that are superior to those of its competitors. This superiority might then translate into increased market share and increased revenue. Network companies operate in a lower risk environment. Their primary goal is to fulfil their obligations as specified in the Electricity Law, in a cost effective manner and with good quality of service. The risks and costs of investment are transferred to customers via the regulated tariffs.

Network companies have to make difficult decisions when forecasts with various degrees of uncertainly show that large amounts of new electricity generation - presumably based on renewable sources - must be connected in the future. Long-term investments to strengthen the grid must then be made in a cost-effective manner. Investment plans must be drawn up so that in the future, the network company will be in a position to connect renewable generation plants in a cost-efficient and timely manner. These investments are risky for network companies since they tie up capital in facilities that will only yield revenues if and when the applications to connect the new generation facilities start coming in.

The risks involved are different from normal investment risks in that a network company does not have to worry about losing customers to other network companies. Once a generator company has decided to build a facility at a particular location, it cannot go to another network company if it is unhappy with the services of the local network company. However, if network companies do not make the necessary investments, it might be difficult to connect new generation in a timely and cost-effective manner. New generation projects could be delayed or cancelled altogether. Generation projects might be cancelled when both the generator and network companies try to minimize their respective risks.

New rules in the Electricity Law (Chapter 4, 11-13 §§) place additional requirements on network companies in order to make it easier for generator companies to have their plants connected to the grid. Network companies are obliged to inform generators how long it will take to process an application to have a generation facility connected, how long it will take to actually connect the facility, and how the costs should be distributed among the different actors if it becomes necessary to strengthen the grid in order to connect the facility. The Inspectorate has been given a mandate by the government to create detailed rules governing these processes. In practice, the new rules mean that network companies will have to give connection applications a higher priority.

Another tool available to the Inspectorate to stimulate investment in smart grid technologies is the creation of so-called quality incentives. A proposal for how quality incentives might work is presented in section 6.2. Briefly, a quality incentive is a mechanism that allows network companies to raise prices if they modify their grids so that it becomes possible to provide a number of so-called intelligent services. The new regulatory framework also allows network companies to add the installations associated with such investments to the asset base. Quality incentives should thus be viewed as additional incentives that can be used to promote adoption of smart grid technologies.

One important factor that deserves attention is how network companies use tariffs to distribute the allowed revenue among different customer segments. The Electricity Law gives network companies considerable freedom in how they charge customers. As long as tariffs are objective and non-discriminatory (see Section 6.3 for details) network companies are free to distribute costs among their customers in any way they see fit. The costs to be distributed, and therefore the allowed revenue, can vary significantly between different network companies. These differences arise for various reasons, but customer density is one important factor. In rural areas with few customers the cost per customer is generally higher than in urban areas. Some differences in cost can also be explained by technical choices that were made in the past. To summarize, the cost for a particular grid service can vary widely between different network companies. These differences are likely to remain and may even grow as network companies invest in smart grid technology.

If the investment environment that the new regulatory framework provides does not produce the desired adoption of smart grid technology, it may be necessary to consider subsidies. These might take the form of government-sponsored subsidies to innovation projects that support renewable electricity generation and/or small-scale electricity generation connected directly low voltage grids. Currently, too little is known about the relation between costs and benefits of smart grid investments. So even though subsidies are a possibility, the financing options available via the new regulatory framework remain as the preferred mechanism for smart grid deployment for the time being.

Right now the focus should be on demonstration projects. Smart grid investments are generally seen as too risky, but if such investments are not made, it will not be possible to know how well the new technology works. Therefore, a number of demonstration projects financed by the state should be conducted. The financing should come via a number of different government programmes and be administered by government agencies such as the Swedish Energy Authority and Vinnova (the Swedish governmental agency for innovation systems). It is very important that existing and planned research activities about smart grids are coordinated with these demonstration projects, and mechanisms and regulatory frameworks have to be put in place to ensure that this happens. It is also very important that the results of demonstration projects are disseminated to all relevant parties.

6.1.5 Summary of conclusions

The Inspectorate is of the opinion that the new regulatory framework coming into effect 2012 will not act as a barrier to smart grid adoption. The Inspectorate is also of the opinion that the ex ante nature of the regulatory framework will create conditions that facilitate a transition to a sustainable energy system. The Inspectorate finally believes that both the Government and the private sector should finance smart grid demonstration projects to ensure that the results from demonstration projects are disseminated to all relevant actors.

6.2 Incitement regulation for smart grid investments

The previous section described the new regulatory framework and how investments made by network companies are treated within this framework. It also discussed how the new regulatory framework might be used to stimulate investments in smart grid technologies.

6.2.1 Influencing investment decisions

Authorities have two ways to influence the investment decisions made by network companies. On the one hand, the authorities can place obligatory requirements (detailed or functional regulation) on network companies. On the other hand, authorities can create financial incentives to stimulate certain kinds of investments (incentive regulation). In Sweden, authorities have used both methods at different times. One example of functional regulation is the requirement that electricity meters must be read at least once per month. Even if the requirement did not specify that any particular technology be used, the effect has been that every network company replaced old electromechanical meters with remotely-readable meters. This in turn led to considerable technology development in the area, and has also resulted in creating a pool of people that are skilled in this particular technology. An example of incentive regulation is the quality incentives mechanism that is part of the regulatory framework that comes into effect in 2012. This mechanism creates a dependency between the tariffs that network companies can charge their customers, and the quality of service provided. The Inspectorate is of the opinion that such regulation can also be used to stimulate smart grid investments.

6.2.2 Quality of service requirements and smart grids

The Inspectorate is of the opinion that incentive regulation should be the main mechanism to ensure that network companies make the smart grid investments that will be needed to adapt the electricity network to the needs of the sustainable energy system. If incentive regulation does not produce the desired results, it might be necessary to use other regulation methods such as functional regulation in the future. The Inspectorate will continue to evaluate the need for new forms of regulation as the technology develops.

The Inspectorate believes that the proposed incentive regulation for smart grids should be modelled on the incentive regulation for quality of service as far as possible. If network companies are allowed higher revenues provided they develop or use new products and services, these companies will be able to better manage the risks associated with smart grid investments.

Chapter 5, 6 § of the Electricity Law states: *"When allowed revenues are set, the quality of service provided shall be considered. Such a consideration may lead to higher or lower returns on investment on the asset base." It also states: "The Government or the Energy Markets Inspectorate may specify the rules that define what is meant by the term "quality of service".*

This last sentence gives the Government or the Inspectorate the opportunity to define quality of service so that it includes the ability of network companies to support a transition to a sustainable energy system. The Inspectorate is of the opinion that the Electricity Law makes this interpretation of quality of service possible, so the Electricity Law does not have to be modified in order to define quality of service in this way.

The above text from the electricity law derives from a Government Proposition on ex ante regulation of network companies[117]. In Section 6.3 of this Proposition, the government states that: *"In addition to price, quality of service is also important for customers. Quality aspects can also be used to steer investments made by network companies towards a predetermined optimal socioeconomic state. This state should correspond to the quality that customers are prepared to pay for."*

The proposition also states: *"This relates to factors over which network companies have direct control, such as the quality of the transport, which is manifested in measures such as interruption frequencies and voltage quality."*

Finally the Proposition states: *"Currently the definition of quality is based on interruption frequency and voltage quality. However, it should be possible to extend and modify the definition of quality in the future to include other measures, such as the quality of the customer support offered by network companies. What is meant by quality should be allowed to change over time. As proposed by the Energy Networks Inquiry, the electricity law should not restrict the set of possible interpretations of the term quality. "*

The Inspectorate interprets the statements in the electricity law and the statements in the Proposition to mean that it is perfectly possible to redefine the meaning of the term quality. The only restriction is that quality measures must be defined so that network companies have the ability to actually influence them.
Various proposed new quality measures will be described below.

6.2.3 Possible Quality metrics for smart grids

The purpose of the proposed incentive regulation is to encourage network companies to seek out solutions that support the transition towards a sustainable energy system. For example, this could mean measures to support large volumes of renewable electricity generation and large numbers of electric vehicles that are charged from the grid. The regulation should focus on functionality and be technology neutral, giving network companies the freedom they need to select solutions that make the most sense from a technical and financial standpoint. From a customer point of view, it is not interesting how a particular service is delivered. In its report on smart grids ERGEG lists quality indicators related to services that smart grids are expected to provide[118]. Some of the indicators that are relevant to this report are:

- Quantified reduction of carbon emission,
- Hosting capacity for distributed energy resources ('DER hosting capacity') in distribution grids. Allowable maximum injection of power without congestion risks in transmission networks,
- Energy not withdrawn from renewable sources due to congestion and/or security risks,
- Share of electrical energy produced by renewable sources,
- Level of losses in transmission and in distribution networks (absolute or percentage),

[117] Government proposition 2008/09:141, Förhandsprövning av nättariffer, March 5th 2009.
[118] Position paper on smart grids – an ERGEG public consultation paper. Ref: E09-EQS-30-04, 10 December 2009, page 33. Position paper on smart grids – an ERGEG conclusions paper. Ref: E10-EQS-38-05, 10 June 2010, page 25.

- Ratio between minimum and maximum electricity demand within a defined time period (e.g. one day, one week),
- Demand side participation in electricity markets and in energy efficiency measures,
- Percentage of consumers on (volunteer) time-of-use / critical peak / real time dynamic pricing,
- Measured modifications of electricity consumption patterns after new (volunteer) pricing schemes,
- Percentage of users available to behave as interruptible load,
- Percentage of load demand participating in market-like schemes for demand flexibility,
- Percentage participation of users connected to lower voltage levels to ancillary services.

ERGEG also states that they believe that the number of smart meters installed should not be a quality measure. The introduction of new technology should not be a goal in its own right, only a means to achieve other ends, in this case a transition to a sustainable energy system.

Most the indicators listed above are also recommended by ENTSO-E and EDSO in their roadmap towards the European electricity system of the future[119].

The indicators that are finally selected for inclusion in an incentive programme must satisfy certain criteria. Indicators must be objective, and it must be possible to measure the effects in an accurate and reliable fashion. Network companies must also be able to actually influence the indicators. Furthermore, the effort required to actually measure the effects must be reasonable in comparison with the benefits derived from the service.

It is also important that selected indicators are defined correctly and unambiguously, and that the definition is useful in determining how incentives are constructed. Some of the indicators listed above are relatively simple to define, whereas others will require further work in order to arrive at a solid definition.

Furthermore, it must be possible for network companies to actually influence the value ogf indicators that are included in the incentives programme.

For instance, while it is possible to measure network losses, doing so with adequate accuracy is difficult since evaluating the indicator involves calculating a small difference between two very large numbers [120]. Furthermore, network losses are not entirely under the control of network companies themselves - they also depend on how consumption varies over time.

Another example is hosting capacity, which cannot be measured since there are so few renewable electricity generation plants connected to the grid today. In order to determine if a network company has met its hosting capacity obligations one

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[119] ENTSOE, EDSO, The European electricity grid initiative (EEGI), Roadmap 2010-18 and detailed implementation plan 2010-12, 25 May 2010, page 21.

[120] If losses are 30 kWh for every1000 kWh of demand, a measuring error of 0.5% results in an error of 7 to 10 kWh for the losses, i.e. almost 30%.

would therefore have to perform a number of calculations that rely on assumptions about the properties of the renewable electricity generation plants that will be connected to the grid in the future. The method to perform such calculations is generally considered immature and in need of further development.

The amount of renewable electricity generation connected to the grid is easy to measure, but it is difficult for network companies to influence the value of this indicator.

The Inspectorate recommends that steps are taken to develop methods to measure and compute suitable indicators. This work should be done at a European level. For instance, it could be conducted within one or more of the three prioritized areas in the European Electricity Grid Initiative[121]: "Integration of small renewable in the distribution network"; "System Integration of medium size renewable"; and "Integration of electric vehicles". In parallel with this work, there should also be work to define suitable indicators for Swedish circumstances.

6.2.4 Timescale for introducing incentives regulation for smart grids

The analysis above shows that considerable efforts will be required to develop suitable indicators for inclusion into an incentive-based stimulus scheme for smart grid adoption. If such schemes are introduced too early, this might lead to overinvestments in conventional technology. For instance, if hosting capacity were today introduced as a quality measure as part of an incentives-based stimulus scheme, the likely outcome would be that network companies would invest in traditional measures to reinforce their grids since the alternative smart grid technology is not yet ready for general use. It is therefore important that an analysis of the likely consequences is made whenever a new quality indicator is included in the incentives-based stimulus scheme. It is also important that the indicator is constructed so that it gives network companies the correct incentives.

The Inspectorate is therefore of the opinion that incentives-based regulation should not be introduced until the second regulatory period which is 2015-2019.

6.3 What constitutes network operation

According to chapter 3, 1 § of the Electricity Law, a generating plant connected to the distribution network is not considered part of network operation and its costs shall not be part of the network tariffs. However, if a generating plant is solely used to prevent undervoltage or overload in the network, technically it could be considered part of network operation. With smart grid technologies, some installations have dual uses. A network company may use battery storage or load management for grid management purposes, but they may also use them much in the same way as generating plant. Several network companies have asked the Inspectorate whether network companies may own some of the components described in Chapters 3 and 4, since ownership of such components. Such componentw would allow a more effective operation of the grid but it would also allow the owner to compete with generator companies. The Inspectorate is of the

[121] EEGI, s.34-35.

opinion that there is no clear cut answer to that question given the current regulatory framework.

But the core reason for the division between regulated network operations and non-regulated generation and sales activities remains: to guarantee non-discriminatory access to the market. A major principle in this division is that network operations should only include activities that must be conducted as a local monopoly for socioeconomic reasons. Activities that can be developed in a competitive market should remain non-regulated as far as possible.

It is not possible to say for sure whether this division represents a long-term barrier to smart grid adoption given what is currently known about smart grids. The Inspectorate is of the opinion that for the time being, the division does not represent a barrier to smart grid adoption. The Inspectorate further believes that the matter has to be investigated further before the technology develops to the point where the division might become an obstacle to further adoption.

6.4 Structure of network tariffs

Section 4.2.1 contained an overview of the various network tariffs that are offered by Swedish network companies. Network tariffs distribute costs incurred by a network company over the company's customer base. The structure of the tariff can provide different incentives for consumers to modify their consumption patterns.

Analysing network tariffs is important for two reasons:

- New technologies such as interval metering and two-way communication provide new opportunities for tariff structures.
- Different tariff structures give consumers different incentives and can therefore impact the four major targets of this investigation in different ways

6.4.1 Network companies face few restrictions in how they construct network tariffs

Chapter 5, 1 § of the Electricity Law states that the allowed revenues of network companies shall be determined ex ante for a fixed regulatory period. The allowed revenue limits the revenue network companies are able to earn from their customers but it does not say how tariffs should be structured. Network tariffs are treated in Chapter 4 of the Electricity Law, which places the following requirements on network tariffs:

- 1 § : Network tariffs should be objective and non-discriminatory. Chapter 5 contains rules for how allowed revenues are computed.
- 2 § : Network tariffs for the transport of electricity shall be structured so, that a paid connection charge gives the right to use the national electricity network, with the exception of interconnectors to neighbouring countries
- 3 § : Network tariffs for the transport of electricity cannot be structured taking into account the location of the connection point within the country
- 9a § : Network tariffs for connection to a line or a network shall be structured so that justifiable costs incurred by the holder of the concession are covered. The geographical location of the connection point and contracted power at the connection point shall be taken into account.

Summarizing, the Electricity Law only places two demands on network tariffs: that they be *objective* and *non-discriminatory*. As long as these two requirements are met, network companies are free to set network tariffs as they see fit. The Inspectorate sets the size of the total allowed revenue, but does not decide how network tariffs are structured.

6.4.2 Current structure of network tariffs

The Inspectorate conducted a survey of existing network tariff structures in 2007[122]. The following types of tariffs were found:

- Most Swedish network companies have tariff structures that include a fixed fee plus an additional fee proportional to the amount of electricity consumed. Customers can influence the latter part by reducing the amount of electricity consumed
- One network company had removed the fixed fee for consumers living in apartments or small houses. Such customers paid a fee proportional to the amount of electricity consumed.
- Six network companies had tariffs where the second component was not present for household customers. They only pay a fixed fee proportional to the size of the fuse.
- A few network companies had introduced domestic tariffs that were similar to load tariffs. The tariff included a fixed fee plus an additional fee. Again, the fixed fee was proportional to the size of the fuse, which determines the consumer's maximum demand. The additional fee was a load charge designed to capture how much of the capacity of the grid a particular customer used.

Network tariffs have not changed must in the recent past. The only significant change is that the number of network companies that use load tariffs has increased. This may be due to the fact that an increasing number of network companies have installed smart metering systems with support for hourly meter reading. Another possible reason is that local network companies are themselves subject to load tariffs when they are connected to regional grids. The Inspectorate does not know if the companies that have introduced load tariffs have done so because they want to minimize the risk of overloading their grids or if there were other reasons. In the future, if the electrification of the transport sector and other changes in society result in an increased demand for electricity, the use of load tariffs can reduce the risk for overloading the grid, and thus also reduce the need to invest in costly measures to reinforce or expand the grid.

Most network companies use load tariffs for their larger customers (high voltage consumers or those on 63 A or above). Some sample load tariffs were described in Section 4.2.1

No network company has tariffs where customers pay a fee that varies as the overall load on the grid varies. There are also no tariffs where momentary local surpluses or deficits of renewable electricity affect the fees paid by consumers. The Inspectorate is not aware of any network company that intends to introduce such tariffs in the immediate future.

[122] Utveckling av nättariffer, 1 januari 1997 – 1 januari 2008. Energimarknadsinspektionen, 19 June 2008.

6.4.3 Alternative network tariff structures and their consequences

Different tariff structures can create different incentives and have different consequences for both customers and network companies, both short and longer term. For example, some tariff structures can give customers incentives to adjust their consumption so that the costs incurred by network companies for network operation and planning are reduced. These cost savings could eventually also lead to reduced costs for the customers. When considering different tariff structures, it is important to consider the consequences for all stakeholders: customers, network companies, and society at large, as the consequences for these stakeholders may either converge or diverge. Currently, most network tariffs in Sweden include a fixed fee (SEK/year), a fee that is proportional to the amount of electricity consumed (SEK/kWh), and a load charge (SEK/kW). Some possible tariff forms and their corresponding consequences from the point of view of the four targets laid out in this report are:

- If the fixed part is reduced customers are given more power over their network costs and may as a consequence become more active
- When the energy part is dominant customers are given strong incentives to increase energy efficiency to reduce consumption. It also creates a strong link between electricity consumption and network company revenues
- A tariff where the fixed part dominates provides network companies with stable and predictable revenues.
- If the energy part is eliminated the revenues of network companies no longer depend on electricity consumption. In such a scenario, it would be interesting for network companies to offer energy efficiency services to its customers.
- Time of Use (TOU) tariffs give customers incentives to shift load from periods when the grid is heavily loaded to periods with lighter loads. This reduces peak loads and reduces the need to make investments to reinforce the grid.
- Load tariffs give customers incentives to reduce their own maximum demand. This might lead to reduction of overall peak loads.

If TOU tariffs or load tariffs were to be introduced on a large scale, it might create incentives for customers to modify their behaviour in such a way that it becomes possible for network companies to reduce or postpone investments in grid reinforcement. However, these tariffs will require high resolution interval metering, like hourly metering.

To summarize: network tariffs can be constructed in many different ways. Different tariff structures create different incentives for both customers and network companies. The choice of network tariff has profound consequences for the way that consumption is measured. TOU tariffs and load tariffs will require metering solutions that provide high resolution interval metering, like hourly metering.

6.4.4 Regulating the structure of network tariffs

It is worth repeating that network companies are currently free to construct network tariffs in any way they see fit as long as the tariffs are objective and non-discriminatory. Access to hourly meter readings will enable network companies to construct new network tariffs and a number of network companies have already done so. In the future it is expected that network tariffs will emerge. It is the responsibility of the network companies to ensure that these tariffs give long-term economic benefits for both network companies and their customers.

A question for the future is whether authorities should become more engaged in the structure of network tariffs. The Inspectorate believes that this question cannot be answered right now, mainly because of a lack of relevant information. There is a lack of quantitative information about the advantages and disadvantages of tariffs currently available in Sweden and of tariffs that will be introduced in the immediate future. In addition, there is too little information about which incentives will be required to engage customers in their electricity consumption.

It is also worth pointing out that there still are technical – and possibly legal - obstacles to some of the network tariff structures that have been discussed. Introducing load tariffs on a large-scale will require more smart meters and the communication infrastructure needed for hourly metering. As more and more consumers are metered hourly, it should become easier to introduce load tariffs.

To summarize: The Inspectorate is of the opinion that further studies are required to determine if authorities should try to exert more control over the way network tariffs are structured. Properly designed network tariffs can give customers incentives to adjust their consumption patterns in ways that will benefit society as a whole.

6.5 High-level national action plan

Earlier chapters have described how the transition to a sustainable society will affect the electricity networks. These chapters also describe how progress in smart grid development and deployment so far has been very modest. Finally, a number of barriers to smart grid adoption are presented.

The transition to a smart grid that is capable of supporting large volumes of renewable electricity generation is going to require significant technical changes to the grid as well as substantial investments. It is not obvious that the transition will happen if market participants are left to their own devices. A better and faster way might be to create a national action plan for the transition to smart grids.

A historical study of national action plans published by the Government shows that national action plans for the energy sector are rare. Different governments and authorities have instead relied on policy instruments to encourage desired transitions. These policy instruments include grants, tax breaks and certificate mechanisms.

National action plans are far more common outside the energy sector. Action plans are usually drawn up to counter serious threats to society at large. For instance, there have been action plans for fighting multi-resistant bacteria and actions plans to stop the spread of epidemic diseases[123].

[123] http://www.regeringen.se/sb/d/2389/a/51911 and http://www.regeringen.se/sb/d/108/a/138397

There have also been national action plans for IT strategies for the health care sector, for gender equality issues, for handicap issues, and for policies directed at the elderly[124]. What these areas have in common is that they are handled at local government level but there is a need for consistency across the country. Local initiatives would have been wasteful, and it was decided that goals and methods that could be applied across the country should first be developed at a national level.

There are several reasons for why it would be rational to create a national action plan for the transition to smart grids and smart metering. If the grid is going to be able to support large volumes of renewable electricity generation, the entire grid must be transformed. Local initiatives that lead to suboptimal solutions on a national level are not defendable from a socioeconomic perspective and might lead to unacceptable delays. The transition will require very substantial investments. If the transition does not take place, the long-term consequences could be severe.

Naturally, a national action plan must be formulated in a way that does not constrain the deregulated electricity market or the equipment market. The plan must also address every part and every voltage level of the national grid.

The work to formulate the national action plan should be led by an actor that has intimate knowledge about how both transmission and distribution grids work. The actor must also have detailed knowledge of how the Swedish electricity market works. Currently, the best candidate is Svenska Kraftnät, the Swedish Transmission System Operator.

The formulation of the national action plan should be followed by a phase where the actual deployment of smart grid technology begins. It is worth considering if the transition from one phase to the next should be synchronized with the execution of one or more large-scale demonstration projects.

Demonstration projects can be dually financed. The state can contribute with some of the funds and the private sector with the rest. Dual financing has been successfully used in the past, for instance when technologies for renewable transportation fuels were developed and commercialised[125].

6.6 Lack of knowledge and skills

Most actors agree that one of the major obstacles to smart grid adoption is a general lack of knowledge. In the discussions carried out during this investigation lack of knowledge was brought up repeatedly. At the end of the day the problem boils down to a lack of critical skills in the work force. In one sense, it is the responsibility of individual actors to make sure that they have a work force with the skills required to meet the future challenges facing the electricity sector. On the other hand, a skill shortage is also a problem for society in that it may slow down adoption of smart grids.

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124 http://www.regeringen.se/sb/d/10671 , http://www.regeringen.se/sb/d/9237/a/145431 , http://www.regeringen.se/sb/d/3107/a/18483 and http://www.regeringen.se/sb/d/12838/a/140499

125 http://www.pff.nu/templ/page____57.aspx

In the discussions that were held in the course of this investigation it became clear that the problem could be described in terms of a deficit, but also in terms of a need:

- Lack of knowledge and a lack of skilled personnel
  a) There is a lack of skilled people that know how the existing electricity system works. There is a deficit concerning both overall knowledge of the electricity system as well as detailed knowledge about various components.
  b) There is a lack of knowledge about how new types of generation and new loads will affect the electricity grid in the future.
- A need for new knowledge and new skills
  c) There is a need to learn more about the interaction between the electricity market and the electricity grid.
  d) There is a lack of knowledge about the needs for, and possibilities of new technology.
  e) There is a general feeling that the future is too uncertain for investment decisions to be made.
  f) There is no clear agreement on what is included in the smart grid concept.

6.6.1 Lack of knowledge and lack of skilled personnel

The electricity system is a large and complex system with complex interactions between electricity networks, production facilities, and consumers. Understanding this complex system requires knowledge about the technical, financial, and legal aspects of the system. Furthermore, different skills are required at different levels. The skills required for operation and planning of local distribution grids are different from those required for operation and planning of the transmission grid. As the electricity system becomes even more complex through the introduction of new type of generation facilities, different customer categories and new technologies, there will be a need for both deepened and widened skill sets. Furthermore, most stakeholders in the electricity sector will feel these needs. Network companies, large generators, industrial customers, energy consultants, and authorities will all need a highly educated work force. The need will be felt at all levels in an organization. Power engineers, technicians, assembly personnel, IT specialists, customer care specialists, lawyers, and business people will all need to both deepen and widen their skills.

Balancing demand for skill with supply is supposed to be handled by the job market. Currently the demand for people with the right skills far exceeds the supply. Since it often takes several years to complete an engineering or business education it may turn out that the job market may fail to balance demand and supply and government intervention may be necessary.[126]. An analysis of this is however outside the scope of this investigation. The situation is made worse by the fact that large numbers of skilled employees will retire in the next few years. In a labour market study from 2007, Svensk Energi (the association of Swedish electricity companies) Svensk Fjärrvärme (the equivalent for district heating) and the two employer organizations EFA and KFS, found that the energy sector needed

[126] Marknader med sökkostnader, Ekonomipriset 2010, Kungl. Vetenskapsakademien, http://kva.se. Arbeidsmarkt is geen markt (arbetsmarknaden är ingen marknad, på Nederländska), De Limburger, 12 October 2010.

to hire 7000 new employees in the period 2008-2014, when the last baby-boomers retire[127].

It might therefore be worthwhile to investigate if the power engineering programmes offered at Swedish universities are sufficiently geared towards providing the skill sets that will be required as the electricity system is transformed. This investigation can be coordinated with the efforts to coordinate research and development activities as the universities involved in this coordination effort are also the universities that offer the power engineering courses.

The Inspectorate has no other proposals on how to solve the skills deficit and is of the opinion that it is up to the actors in the electricity sector to solve this problem.

6.6.2 The need for new knowledge and new skills

This investigation has pointed out a lack of understanding of how new generation technologies and new loads will affect electricity grids. One of the consequences of this lack of understanding is that the most complex and problematic scenarios are often presented as typical situations even though they may only occur very seldom. This in turn may lead to overly protective and conservative behaviour from actors in the electricity market. There is also too little information on how generation and demand will develop during the period 2020-2050. There is also uncertainty over future requirements on infrastructure, on the business models that will prevail, and on the role of network companies in the future. There is further considerable uncertainty about the possibilities and benefits that can be expected from smart grid technology.

There is a wide spectrum of technical solutions that can be used to support the integration of new forms of supply and demand into the electricity network. Some of these technologies have been on the market for a long time, while others are still at the research or development stage. There is considerable uncertainty surrounding the possibilities as well as the maturity of many of these technologies. This uncertainty can also lead to overly protective and conservative behaviour and thus act as a barrier to investments in new technology that is more cost effective in the longer term.

As results from research, development, and demonstration projects become available it is expected that it will become easier to evaluate the possibilities and potential benefits of the new technologies. It should also become easier to steer developments in directions that maximize benefits for society at large.

The research and development initiatives that will be required to support a transition to a sustainable energy system cover a wide spectrum of problem areas that have traditionally been covered by different research disciplines. These disciplines are usually financed by different sources and there is little or no coordination between the disciplines. The Inspectorate is therefore of the opinion that smart grid research and development currently suffers from a lack of clear prioritizations, a lack of central control, and a knowledge platform that can be used

[127] Energibranschen behöver nyanställa 7 000, ERA, http://www.era.se/nyh/vn.shtml?id=611579684

to exchange insights and results from different research and development projects. The Inspectorate also feels that there is a lack of coordination between diverse fields such as information technology, communication technology, market models, and power engineering. It is also important that insights and research results are made available to all interested parties. The Inspectorate is of the opinion that it is important to prioritize research and development that can be used to transform electricity grids so that they can support a transition to a sustainable energy system. The results of research and development projects should also be disseminated as early as possible.

6.6.3 - The need for more research and development in the energy sector

There is a need to continuously refine existing knowledge about energy markets and about how the existence of regulated monopolies affects the energy markets. This research should cover issues such as how legal frameworks should be formulated, how roles and responsibilities in the energy sector should be structured, and how regulatory frameworks affect both network companies and the companies that participate in the deregulated part of the electricity market. As energy markets in the Nordic region and the EU are harmonized, the need for this kind of research will increase.

This research is also highly relevant for the transition to a sustainable energy system. For example, it is expected that a transition to a sustainable energy system will require that electricity customers play a more active role in markets for electricity and ancillary services but at present there is little knowledge about potential new commercial arrangements. Furthermore, there is too little ongoing research into how market dynamics and regulatory frameworks are developing. The need for knowledge on these issues is expected to increase in the future.

6.6.4 The need for of a common understanding of what smart grids are

During the course of this investigation it became clear that there is no common understanding of what the terms "smart grids" and "smart metering" actually mean. Several actors felt that the smart meters were rolled out for the sake of the technology itself, rather than as a means to achieve certain goals.

The Inspectorate feels that it is important that the concept of smart grids is defined clearly and unambiguously, and in such a way that it becomes clear what their purpose is. Our definition is based on the four major goals of this investigation, as well as on the definition used by ERGEG:

Intelligent or smart grids is the synthesis of technologies, functions, and regulatory frameworks that in a cost effective manner facilitate the introduction and use of renewable electricity generation, the reduction of overall energy consumption, the reduction of load peaks, and the creation of an environment where electricity consumers can become more active.

7 Metering requirements

This investigation is a consequence of government decision N2010/1762/E. According to this decision, the following should be part of the investigation: *"Investigate to what extent the new functions that will become available as a result of the smart meter deployment can be used. Furthermore investigate for which smart metering functions it might make sense to formulate minimum functional requirements".*

The Third Package[128] contains provisions regarding smart metering. The goal expressed in the Third Package is that smart metering should facilitate providing customers with information about their own consumption and aid in making customers more aware of their own electricity consumption. According to the Third Package, *"Member States shall ensure the implementation of intelligent metering systems that shall assist the active participation of consumers in the electricity supply market. The implementation of those metering systems may be subject to an economic assessment of all the long-term costs and benefits to the market and the individual consumer or which form of intelligent metering is economically reasonable and cost-effective and which timeframe is feasible for their distribution."*

7.1 Benefits of smart metering

Smart metering systems can support the four starting points of this investigation in various ways: they can facilitate the introduction of renewable electricity generation, create the conditions for load reductions, increase energy efficiency, and give electricity customers the opportunity to become more active participants in the electricity market. How these different functions interact long-term will be described below. Before new advanced functions are introduced, a cost-benefit analysis should be performed, since the costs involved are substantial. These costs will have to be borne by the network companies and ultimately by their customers.

7.1.1 Facilitate increased use of renewable electricity production

- *A mechanism for net billing*[129] to increase the financial attractiveness of own electricity production. Customers that generate electricity should have the possibility of offsetting imported and exported electricity. They should also be able to sign deals with electricity suppliers to sell excess electricity.
- *Interval metering* (hourly metering[130]) and remote meter reading to support advanced tariff structures. Tariffs can be designed to encourage local renewable electricity generators to quickly increase or decrease generation based on demand and price.
- *Customer control of metering data.* If metering data is made available via an open interface customers can access their own consumption data. Customers could

[128] Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC, http://eurlex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2009:211:0055: 0093:EN:PDF

[129] "Nettodebitering - Förslag till nya regler för användare med egen elproduktion", EIR 2010:23

[130] "Ökat inflytande för kunderna på elmarknaden - Timmätning för elkunder med abonnemang om högst 63 ampere", EI R2010:22

also grant access to their consumption data to third parties offering innovative energy services, e.g. control of small generators located at customers premises.

- *Remote control.* Direct control of consumption and generation in response to local surpluses or deficits of renewable electricity.
- *Two-way communication* between smart meters and market actors could be used to control the amount of electricity produced by small generators. For instance, informational messages about the need for balancing services could be sent to owners of small generation facilities.
- *Home interface.* Provide electricity customers with information about their own consumption or production .

7.1.2 Reducing peak loads

- *Interval metering* (hourly metering) and *remote meter reading* to support suitable tariff structures. These tariffs can encourage customers to shift their consumption from periods with high demand to periods with lower demand. Can be used in conjunction with two-way communication, remote direct control, and home interfaces.
- *Two-way communication* between smart meters and market actors could be used to control demand and generation.
- *Home interface.* Provide electricity customers with information about their own consumption and local load peaks. Facilitates direct control of loads at customer premises to reduce demand.
- *Consumer control of metering data.* If metering data is made available via an open interface customers can grant third parties access to their consumption data. These third parties can offer load management services.

7.1.3 Energy efficiency

- *Interval metering* (e.g. hourly metering) and *remote meter reading* to support suitable tariff structures.
- *Two-way communication* between smart meters and market actors could be used to control demand and generation. It can also be used to provide customers with information about local load peaks. Finally it could be used for direct load control.
- *Home interface to p*rovide electricity customers with information about their own consumption and current price levels. Facilitates direct control of smart home appliances.
- *Customer control of metering data.* If metering data is made available via an open interface customers can grant third parties access to their consumption data. These third parties can offer innovative load management services.

7.1.4 Active customers

- *Interval metering* (hourly metering) and *remote meter reading* to support suitable tariff structures.
- *Two-way communication* between smart meters and market actors could be used to control demand and generation.
- *Home interface.* Could be used to disseminate price information to customers. Could also be used to control smart appliances that automatically adjust load depending on changing price levels.

- The opportunities to use these advanced smart meter functions to reach the four main goals of this investigation are summarized in the following table:

Table 6.1 Possibilities of advanced metering functionality

	Facilitate increased use of renewable electricity production	Load reductions if load peaks	Energy efficiency
Interval metering (e.g. hourly metering)	Supports innovative tariff structures. These tariff systems can create incentives for local generators to increase or decrease generation based on demand and price	Encourage consumption reductions during peak periods. Can be used together with two-way communication, remote control and home interface.	Encourage shift of discretionary load to off-peak periods when price is lower.
Net billing	Increases the financial attractiveness of own electricity production. Customers that generate electricity should have the possibility of offsetting imported and exported electricity. They should also be able to sign deals with electricity suppliers to sell excess electricity.	Encourage increase in output when possible	Incitement to use own generation
Customer control of metering data	If metering data is made available via an open interface customers or an authorized third party can access consumption data. Third parties can develop innovative services to remotely control smaller generation facilities located at the customer premises.	If metering data is made available via an open interface customers or an authorized third party can access consumption data. Third parties can develop innovative services to e.g. disconnect loads at customer premises.	If metering data is made available via an open interface customers or an authorized third party can access consumption data. Third parties can develop innovative services to remotely control loads at customer premises.
Remote reading of generated and consumed electricity	Information to the network companies and the system operator on a sites input and output pattern makes the innovative tariffs possible	Information to the network companies and the system operator on a sites input and output pattern makes load management possible	
Two-way communication	Can be used to control the amount of electricity produced by small generators. For instance, informational messages about the need for balancing services could be sent to owners of small generation using this communications channel.	Information to customers on local load peaks, possibility for load management	Can be used to control demand following price signals
Remote control	Direct control of consumption and generation in response to local surpluses or deficits of renewable electricity.	Generation can be reduced at peak times.	
Home interface	Provide customers with feedback about their own generation	Provides customers with information about their own consumption and local load peaks. Facilitates direct control of smart home appliances to reduce demand as necessary.	Provides customers with information about their own consumption and current price levels. Facilitates direct control of smart home appliances.

7.2 Will new minimum functional requirements be required

The Inspectorate is of the opinion that minimum functional requirements, beyond those functions needed for the implementation of hourly readings of domestic customers, net billing, and customer access to consumption data, are not necessary or desirable at the moment, an opinion that The Inspectorate shares with the authors of the NELGA[131] investigation. The main reason for not formulating any new minimum functional requirements is that there are several on-going EU projects that are working on functional requirements and standards. It would be

[131] SOU 2010:30, Nya el och gasmarknadsutredningen

better to wait for these projects to present final results before considering further work on minimum functional requirements. However, the Inspectorate feels that work on functional requirements related to consumption feedback for household consumers should be conducted during 2012. Below are brief descriptions on some of the EU projects that are being closely followed by the Inspectorate. The Inspectorate is an active participant in these projects.

7.2.1 Mandate M/441

Mandate M/441[132] is an initiative by the European Commission's Directorate General (DG) Enterprise based on an official mandate from the EU commission to CEN, CENELEC, and ETSI. The mandate was published on March 12th 2009 and tasked CEN, CENELEC and ETSI with developing an open architecture for smart metering. The architecture focuses on communication protocols and interoperability. According to mandate M/441, the interoperability goals will require minimum functional requirements that go beyond those of the MID[133].

7.2.2 Preliminary conclusions according to Mandate 441

Mandate M/441 has identified the following functionalities, with a view to assuring mobility, innovative thinking, and competition:

- Remote meter reading of both injected and consumed electricity - remote reading of metrological register(s) and provision to designated market organisation(s).
- Two-way communication between the metering system and designated market organisation(s)
- Interval metering/registering to support advanced tariffing and payment systems. (There is an on-going debate involving regulatory authorities, network companies, and other interested parties in Europe about the frequency of the meter readings. In Sweden, the regulatory framework requires that profiled sites are metered and registered at least once every month.)
- Remote control to allow remote disablement and enablement of supply and flow/power limitation
- Home interface, home automation (communicating with (and where appropriate directly controlling) individual devices within the home/building)
- Information via web portal/gateway (to provide information via web portal/gateway to an in-home/building display or auxiliary equipment)

Recommendations from ERGEG

ERGEG published the "Final Guidelines of Good Practice on Regulatory Aspects of Smart Metering for Electricity and Gas"[134] on February 8th, 2011.

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[132] Standardisation mandate to CEN, CENELEC and ETSI in the field of measuring instruments for the development of an open architecture for utility meters involving communication protocols enabling interoperability, M/441, European Commission, Enterprise and Industry Directorate-General, 12 March 2009

[133] Directive 2004/22/EC of the European Parliament and of the Council of 31 March 2004 on measuring instruments

[134] Final Guidelines of Good Practice on Regulatory Aspects of Smart Metering for Electricity and Gas Ref: E10-RMF-29-05, 8 February 2011

ERGEG decided to develop these recommendations since the Third Package did not provide any detailed information about what smart metering systems should be able to do. In its recommendations, ERGEG focuses on a set of functionalities of the actual meters. ERGEG sees these as important for the development of smart metering technology. It also feels that a focus on the actual meters will ensure an adequate set of minimum services for both ordinary consumers and consumers that sometimes also act as producers.

7.3 Net billing [135]

7.3.1 A growing interest in small-scale electricity generation

There are currently around one thousand electricity customers in Sweden that generate their own electricity. Small-scale photovoltaic (PV) and small wind generators dominate. Many actors have stated that more and more customers are interested in generating their own electricity.

A way to increase the financial support for customers that generate electricity for their home or business is the introduction of a regulatory framework that allows customers to receive payment for exporting electricity at times that they are generating more than they use. The Government commissioned the Inspectorate to examine, in cooperation with Svenska Kraftnät, the issues surrounding and the advantages and disadvantages of different net billing arrangements. If necessary, proposals for changes to the Electricity Law will be submitted.

7.3.2 Settlement in the meter automatically results in net billing[136]

In the description of the government assignment, net metering is described as a way to achieve net billing. Net metering employs a single meter to track both incoming and outgoing electricity with a single register. Monthly net metering, i.e. that a single value is registered and reported every month automatically means that both the network company and the supplier apply net billing.

7.3.3 … but is incompatible with current tax legislation

Net metering is not compatible with existing tax and VAT rules. Energy taxes and VAT shall, according to current rules, be based on a customer’s total electricity consumption, and not on the net difference between imports and exports under a certain time period, e.g. a month. There are, besides tax rules, other barriers to introducing net metering arrangements. Net metering has the potential to make balance settlement more difficult. Net metering also takes away from the producer the possibility to sell its own excess production. If imports and exports are metered and reported separately, suppliers can choose to either buy the electricity injected into the grid or to net-bill based on the difference between imported and exported electricity during the relevant time periods. With net metering the only option is

[135] This section is taken from ”Nettodebitering - Förslag till nya regler för användare med egen elproduktion, EIR2010:23”

[136] Net metering uses a single meter to track both incoming and outgoing electricity with a single register. Microgeneration, usually uses net billing. Net billing employs a meter with two registers - one for electricity fed to the grid and one for electricity taken from the grid. Having two registers allows microgenerators to keep track of how much electricity their installation has generated.

net billing. Against this background the Inspectorate has judged it to be more appropriate that imported and exported electricity continue to be measured and reported separately.

7.3.4 Imports and exports of electricity to the grid should be settled separately and on hourly data

The billing arrangements of network companies and electricity suppliers rely on metering and settlement. Metering and settlement are also prerequisites for Svenska Kraftnät's balancing and settlement arrangements.

Existing rules for hourly metering and hourly settlement of electricity injected into the grid should not be modified. Svenska Kraftnät needs hourly metering and hourly settlement to calculate imbalance settlement charges, something vital for the functioning of the electricity market. No exceptions should be made for customers that generate electricity, as the existing profiling system might not adequately deal with the quantities exported without causing excessive disruption to the system.

The Inspectorate is also of the opinion that electricity consumption at sites where there is both consumption and generation should also be settled on hourly data. The demand patterns of customers that both consume and generate are different from those of other small customers. Mixing these two groups would have negative consequences for balance responsible parties.

7.3.5 An obligation to purchase production is required for settlement to work

The Inspectorate is of the opinion that electricity suppliers that deliver electricity to a site are best-placed to buy the electricity generated at that site and should also have an obligation to purchase it. However, even when the supplier has an obligation to purchase the electricity, this is a non-regulated business and the supplier is free to set his purchasing price, which he can set as low as he wants. The obligation should not imply risks for the supplier. If the producer finds a supplier that offers a better price for the surplus electricity it generates, he can go to that supplier. This arrangement also ensures that the network company always knows which supplier needs the metering data and who the balance responsible party for the site is.

7.3.6 Network companies should net bill network tariffs monthly

Another way to achieve net billing other than network companies read and report a net value is that a site's exports and imports of electricity to the grid are measured and reported separately and that the net value is first calculated for billing purposes.

The Inspectorate proposes an obligation for network companies to base network tariffs on the net value of the electricity imported and exported to the grid during one month. The obligation should concern all sites with own generation with a fuse of max. 63 A that on a given year are net consumers of electricity. Net billing should be done monthly as longer periods would involve invoices that are not based on actual consumption, and the Inspectorate does not find this satisfactory.

A consequence to network companies of the net billing obligation described above is a loss of revenue from network tariffs. Ultimately all customers will pay, in the form of higher network tariffs. However, because the number of customers that generate electricity is currently very small, the Inspectorate is of the opinion that this loss of revenue will be very small compared to a network company's total earnings. This means that the network tariffs of all other users will only be very marginally affected.

For customers that generate electricity, the offsetting of network tariffs will result in a small economic gain. Network tariffs are approximately 20% of an electricity bill, around 25 öre / kWh for an electrically heated house, or 400 SEK per year. The exact amount saved will depend on factors such as the type of generating plant, total demand, and the size of the fixed and variable components of the network company.

7.3.7 Suppliers should not be obliged to apply net metering

The Inspectorate is of the opinion that it is not desirable to introduce an obligation for electricity suppliers to offset imported and exported electricity. This is currently not legally possible, as current tax and VAT rules do not allow energy taxes and VAT to be offset in this way. Furthermore, the obligation would mean that suppliers, that otherwise operate in a deregulated market, would be forced to handle customers with own generation. Worst case, these customers would result in no revenue beyond fixed charges. This could impact the suppliers' ability to compete in the market, and because some suppliers would suffer more than others, the obligation would distort competition between suppliers.

7.3.8 Voluntary market arrangements for net metering or electricity surplus buy back

Customers that generate electricity will have, just as is the case today, the possibility to sign up with a supplier of their choice to sell back surplus electricity. The Inspectorate believes that suppliers will voluntarily offer a range of tariffs to customers wanting to sell back electricity. There are currently suppliers that have stated that they buy back surplus electricity from their customers. It will also be possible for suppliers to offer net metering arrangements to customers if they so wish. However, net metering is not compatible with existing tax rules.

7.3.9 Measures to boost microgeneration must not disturb the way the overall electricity market functions

The regulatory changes the Inspectorate is proposing do not represent major changes for the customers that generate electricity. If a future review of market arrangements deems that the financial incentives for customers that generate electricity are not enough, the Inspectorate is of the opinion that any further action taken to increase incentives should not affect competition in the electricity market or otherwise disrupt the market.

7.3.10 Settlement of the energy tax shall give suppliers incentives to offer net metering

Current tax rules are a barrier to full net billing. In order to facilitate full net billing, as a way to increase the financial rewards for customers that generate electricity, the Inspectorate suggests that the Government commissions the Tax Authority to examine the possibility of a review of the taxation system to allow net billing to include energy taxes and VAT.

Energy taxes and VAT make up around 40% of a customer's electricity bill, which corresponds to approximately 55 öre /kWh for an electrically heated house. The possibility to offset energy tax and VAT would mean that generators could save up to around 800 SEK per year. The size of the savings depends on the generation technology being used and the customer's consumption. For the state, missed revenue from taxation would amount to around 800 000 SEK per year, based on the current number of customers that generate electricity in Sweden. It should be noted, however, that the state's income from VAT would probably increase as improved financial conditions for customers that generate electricity would lead to increased investment in microgeneration installations.

The Inspectorate is of the opinion that allowing suppliers to offset energy taxes and VAT would make it easier for suppliers to voluntarily offer net billing arrangements as offsetting would then apply to all items that suppliers charge their customers.

7.3.11 The electricity certificate system must be modified to support customers that generate electricity

The Electricity Certificate system plays a major role in determining how much electricity generation from renewable energy sources will enter the Swedish electricity system. The Inspectorate has observed, during the course of this work, that the design of the Certificate system does not take the interests of customers that generate electricity fully into account. The current rules make it difficult for customers that generate electricity to claim the Certificates they are eligible for. Hourly readings of the meter measuring total generation are required by Svenska Kraftnät in order to issue the corresponding Certificates. This requirement applies to generation connected to all networks: both those that are operated under concession (i.e. to the grid of network companies) and those that are not. This means that in order to profit from the Certificate system, customers that generate electricity must be hourly metered. This represents an extra cost for producers that risks making obtaining Certificates too expensive.

A possible way to remove this barrier would be to allow consumers that generate electricity to report their total generation themselves to the Certificate system once a month. This would be simpler and cheaper. The Inspectorate is therefore of the opinion that the Government commissions the Energy Authority to examine the possibility of allowing customers that generate electricity that are not connected to networks in possession of concessions to be responsible for the metering and reporting of their own production as required by the Certificate system. Alternatively, a standard value could be used to issue Certificates to small generating plants.

7.4 Hourly metering for domestic consumers[137]

In 2008, the European Commission proposed binding legislation to implement the so-called "20-20-20 targets". These targets lie at the core of the "climate and energy package" that became law in 2009 and also contains discussions on how risks related to climate change should be managed. The climate change package is the base for Directives 2009/28/EC (the Renewable Directive) and 2009/72/EC (the Third Electricity Directive). In Sweden, the European targets have resulted in Government Propositions 2008/09:162 and 163 on climate and energy policies.

7.4.1 The electricity market must develop

The electricity market has the potential to contribute to the achievement of goals such as a lower carbon society, increased use of renewable energy, and improved energy efficiency. Realizing this potential requires that there is an infrastructure and a regulatory framework that allows the actors in the electricity market to act according to the new circumstances.

In order to support the climate change goals while maintaining a functioning electricity market, the electricity market must evolve. The electricity market must be made more efficient by creating more demand side flexibility - an electricity market where customers respond to price signals to a far greater extent than today.

7.4.2 ....hourly meter reading is one step on the way

Increased demand side flexibility not only contributes to meeting the climate change goals. It also makes the electricity market more efficient and makes customers more powerful. The advantages of increased demand side flexibility are several, and affect all participants in the electricity market.

Today, most electricity customers in Sweden do not see an electricity price that reflects the wholesale spot price on the Nordic power exchange. This leads to inefficient resource allocation and acts as a barrier to the realization of several of the potential benefits of the current market design. If demand side flexibility is to become a reality, customers must see electricity prices that are far more correlated with spot prices than today. To make this a reality, hourly meter reading for all or most customers must be implemented.

7.4.3 Hourly meter reading will bring benefits if implemented in the right way

The way hourly meter reading is delivered has a strong effect on how beneficial it is. The Inspectorate has conducted a cost-benefit analysis where a number of different hourly-metering implementations for smaller customers (63 Ampere or less) have been compared. This analysis shows that it is important that the implementation is carried out in the right way. Factors such as which customers to include, and which settlement system is used have a major impact on the final benefits of an hourly-metering reform.

The analysis shows that the choice of implementation method is strongly influenced by the costs involved. The analysis also shows that the current system

[137] This section comes entirely from " Ökat inflytande för kunderna på elmarknaden - Timmätning för elkunder med abonnemang om högst 63 ampere", EIR2010:22

of hourly metering and hourly settlement which is only used for large customers (63 A or above), will not be able to handle significantly larger numbers of customers, and that the system cannot be adapted without incurring significant costs.

Hourly metering and settlement for small customers will only be beneficial for customers and society as a whole if the implementation minimizes costs and maximizes benefits. The cost-benefit analysis shows that the option where all electricity consumers are hourly metered (option 3 in the analysis) is not profitable. This is mainly due to excessive costs related to hourly settlement procedures, but also due to a lack of clear benefits in including the smallest customers. The smallest customers have very small possibilities to make significant positive contributions by reacting to price signals.

The two implementation scenarios that are interesting are a scenario where hourly metering is open to all but optional, and a scenario where hourly metering is compulsory for all customers that consume more than 8 000 kWh per year. The analysis shows that these two alternatives provide socioeconomic benefits that are more or less equal. However, a sensitivity analysis shows that the latter scenario - compulsory hourly metering for all customers that consume more than 8000 kWh per year - is far more likely to become a success. The Inspectorate is also of the opinion that an alternative where hourly metering is optional will lead to far slower adoption rates - this is also evident in the analysis.

However, it should be pointed out that small changes in the parameter values that have been used in the analysis have an impact on the result. It is also important to point out that the Inspectorate has not had the opportunity to consider all potential benefits of hourly metering during the analysis - only those benefits that are directly quantifiable. Several non-quantifiable benefits of hourly metering, such as an improved electricity market, improved price formation, and reduced risks for capacity shortages, have not been included in the analysis. Since these important benefits have not been included in the analysis, it is likely that the actual benefits will exceed those predicted by the analysis.

7.4.4 Hourly metering reading is good for society but many factors point to the need for a gradual deployment

The Inspectorate believes that there are several reasons for a gradual introduction of hourly metering and hourly settlement for smaller customers (63 A or less). One reason is that it is hard to predict when it will become useful to have hourly metering for all customers. The Inspectorate is of the opinion that hourly metering for all customers will not become a necessity in the foreseeable future. Some actors have argued that hourly metering should only be introduced when it is suitable to do so for all customers. The Inspectorate is of the opinion that such an approach would make it considerably more difficult to transform the energy system. The benefits to customers that increased demand-side flexibility would bring would also not materialize in the foreseeable future.

7.4.5 Proposals from the Energy Markets Inspectorate

- All customers for which annual consumption exceeds 8000 kWh should have their consumption "read" and registered every hour.
- Which sites consume more than the 8000 kWh per year threshold should be decided by looking at historical records. If during any year annual consumption exceeds 8000 kWh at a site, that site should from then on be hourly metered, even if consumption after that is lower than 8000 kWh per year.
- The government should commission Swedac to modify the regulatory framework that governs the use of category one meters in order to ensure that these meters are better adapted to hourly metering for electricity customers.
- Hourly settlement for smaller customers (63 Ampere or less) should be designed so that customers are given sufficiently strong incentives to react to price signals from the spot market. A settlement system that supports this goal does not exist, and must be developed. The system must be highly cost effective so that network tariffs are not unduly raised. The government should commission Svenska Kraftnät to develop such a settlement system. The system should be based on the settlement method that goes under the name "monthly hourly settlement" in this report. Efforts should be made to ensure that the new settlement system is compatible with efforts to harmonize retail markets of the Nordic countries.
- Network companies should have the right to apply for temporary exemptions to the hourly metering requirement.
- The Inspectorate believes that the relevant actors will need one and a half years to implement support for hourly metering of small customers. However, the Inspectorate believes that it might be advantageous to synchronize the introduction of hourly metering with the "launch" of the common Nordic retail electricity market. The retail markets of the Nordic countries are expected to be integrated by 2015.

7.5 Meters and metering infrastructure

According to Chapter 1, 4 § of the Electricity Law (1997:857), network companies are responsible for measuring loads and energy flows at all connection points in its area. Network companies are also obliged to perform the necessary calculations on these measurements, and to report the results to the appropriate stakeholders. Currently these measurements are used by network companies for network tariff billing, and by electricity suppliers for electricity consumption billing.

Measurement data can also be used for other purposes. For instance, information about the maximum loads of individual customers can be used in network planning to optimize the design of the grid. This in turn can facilitate the introduction of renewable electricity generation. Such optimizations will in the long term reduce the need for costly investments in new capacity and will therefore be beneficial for both network companies and their customers.

7.6 Customer access to metering data

The Inspectorate shares the view of the NELGA investigation that the Electricity Law should be modified such that network companies become obliged to provide electricity customers with information about their consumption at least once per month. The Inspectorate is also of the opinion that it is preferable to introduce hourly metering for small customers once this modification has been made. Information should be provided in a technology-neutral manner, and at no cost to customers. The Directive states that customers should be provided unconditional and free access to their consumption data, and that they should get the data sufficiently often to enable them to modify their consumption patterns.

Most meters that are installed in Sweden already have the capability to provide several of the advanced functions described in Section 7.1. Use of these functions would facilitate smart grid adoption. However, in most cases these capabilities are not activated. The Inspectorate believes that advanced metering functions should be activated as far as possible; collected meter readings should be made available to electricity customers.

It should be the electricity customer that is in control of his/her metering data. It should be the customer that decides what other parties are granted access to this metering data. The customer also picks the products and services based on this metering data. Network companies could be providers of such services, but should do so on a competitive market - not as a regulated monopoly.

7.7 Third party access to metering data

The Inspectorate believes that third party actors should have access to either the meter or the metering data, if authorized by the customer. Third parties should either be allowed to send remote meter data queries to the meter or queries to the central repository where collected meter data is stored. The purpose is to open up the market for innovative new actors that might use the metering data to provide valuable services to customers, hopefully services that will enable customers to play a more active role in the electricity market.

Access to metering data will only be possible if the third party has received authorization from the customer to access that data. The exception to this rule is that network companies should always have automatic access to the metering data that is essential for operating the grid.

It is reasonable to expect that these third parties should be given access to the same data that is made available to electricity suppliers.

7.8 Summary

A first step towards reaching the four main goals of this investigation:

- Facilitate the further integration of electricity from renewable energy sources.
- Help reduce peaks in electricity demand
- Improve incentives for energy efficiency
- Create an environment where customers can be more active

is to introduce hourly metering which will enable a whole set of innovative products and services to be developed, and new markets to form. The Inspectorate is of the opinion that if these products and services are to become a reality, the smart metering systems must be able to collect hourly meter values from the vast majority of customers.

Hourly interval is also beneficial for network companies since the more frequent consumption data that is collected with such metering can be used in several ways. Network companies will find that it will be easier to do network planning when they have access to this detailed measurement data. It will also become easier to optimize the grid in various ways and to operate the grid in general.

The Inspectorate is also of the opinion that customers should have access to, and control over, their own consumption data. Not only should customers have full access to their own consumption data, they should also be allowed to grant third parties access to this data. Giving customers access to their own consumption data opens up possibilities to create incentives for customers to become more active participants on the electricity market. Giving third party actors access to consumption data might lead to the creation of new products and services. For instance, energy efficiency experts that are given access to consumption data could offer tailored advisory services.

The Inspectorate finally believes that minimum functional requirements on information dissemination services targeting electricity consumers should be formulated during 2012. The purpose of these information dissemination services is to make electricity customers more active in the electricity market.

8 Conclusions and proposals

The transition of the existing energy system towards a sustainable energy system represents a major challenge for society. The electricity grid will play an integral role in this transformation. Transforming the energy sector will involve major changes to the way energy is used and supplied, for example renewable electricity production and electrification of the transport section. The electricity grid will have to be able to transmit electricity reliably even as it sees large increases in intermittent electricity generation from renewable sources and possibly major changes in demand resulting from the electrification of the transport sector. Meeting these challenges will involve fitting the electricity grid with new, smarter technology. The grid will have to evolve into a “smart grid”. Smart grids will be required to prevent overload and overvoltage, and to overall manage greater fluctuations in supply and demand, while maintaining security of supply. With smart grid technologies the grid can be upgraded in a flexible, cost effective manner.

Intelligent networks, or smart grids, is the synthesis of technologies, functions, regulatory frameworks and electricity markets that in a cost effective manner facilitate the introduction and use of renewable electricity production, the reduction of overall energy consumption, the reduction of peak loads, and the creation of an environment in which electricity customers can become more active.

The Inspectorate has identified a number of barriers to the development of smart grids in Sweden. These include a lack of knowledge about smart grids in industry, low prioritization of research about electricity networks, weak incentives to invest in the new technology, a lack of a national action plan for a large-scale transformation of the electricity grid, the structure of network tariffs, and a lack of suitable information services for electricity customers.

This chapter contains a summary of the conclusions drawn by the Energy Markets Inspectorate and a summary of the proposals that are based on these conclusions.

The Inspectorate proposes the creation of an independent council to increase and disseminate knowledge about smart grids. The council should identify the need for new research, development or demonstration projects. The council should also give guidance with decisions on government funding. It is imperative that the electricity network is given the right priority when competing for government funding. The Inspectorate must design the regulation of the network companies to create incentives to promote smarter electricity networks. The Swedish transmission system operator, Svenska Kraftnät, should be given the task to produce a national action plan or road map for the transformation of the electricity network. Network tariffs should be designed so that load and price peaks are reduced. Minimum functional requirements must be formulated on the information provided to customers so that they are better equipped to respond to price signals from the electricity market.

The Inspectorate also is of the opinion that the current division of the grid in trunk transmission network, regional networks, and local distribution networks must be reviewed. The division of the transmission grid into two parts - trunk transmission and regional – can constitute a barrier to an efficient use of the electricity grid. For example, the division can be an issue when planning the connection of renewable electricity generation.

8.1 The establishment of a knowledge platform for the electricity networks of the future

There is currently a general lack of knowledge about the needs for and possibilities of smart grid technology. This investigation has four main starting points, which form challenges to the electricity grid. Adapting the electricity network (at transmission, regional, and local level) so it they can support the ongoing transformation of the energy system into a sustainable energy system presents the biggest challenge. Lack of knowledge is a concrete barrier to this adaptation.

Electricity network research does not have clear funding priorities related to the adaptation of the electricity network to the transition into a sustainable energy system. There is also a need for more coordination between the different research areas that are relevant for smart grids. These areas include information technology, communications technology, market models, and power system engineering.

Based on this, the Inspectorate proposes that:

A knowledge platform is created to coordinate and spread relevant knowledge about research, development, and demonstration to all stakeholders. An independent coordination council is established to manage the knowledge platform.

The council should coordinate the research, development, and demonstration projects that are carried out in order to adapt electricity networks for the transformation of the energy system. The council is also responsible for ensuring that the results of these efforts are disseminated in an effective and timely manner to all interested parties. The council should also coordinate its work with the four persons appointed by the Swedish Government to enable easier contacts between the different stakeholders involved in the deployment of wind power in Sweden ("vindkraftsamordnare" [138]).

The council should be created as quickly as possible and make regular reports on the progress of the projects it is coordinating.
The goals of the knowledge platform are:

- To coordinate all wholly or partially publicly funded Swedish research, development, and demonstration projects into technologies that can be used to transform electricity networks so that they can support the transition towards a sustainable energy system.
- To guarantee that results and other obtained knowledge are disseminated in an effective and coordinated manner to all stakeholders.

[138] http://www.sweden.gov.se/sb/d/2448/a/67186

- To identify needs for new research, development, and demonstration projects, beyond the ongoing ones in Sweden.
- To monitor the progress of research and development activities outside Sweden, and to coordinate relevant international collaborative projects with participation from Swedish authorities, companies, and universities.
- To support the participation of Swedish industry in the development of technologies that can be used to modify electricity networks so that they can support the transformation of the energy system.

8.2 Considerations on the financing of research, development, and demonstration projects

Large-scale demonstration projects can act as a catalyst for developing and adopting innovative smart grid technology. The financing of such projects is therefore vital, as with increased knowledge the risks associated with investing in new and emerging technologies will decrease. However, there is insufficient information at present to determine what kind of demonstration projects are needed, and how potential projects should be prioritized.

There is further a need to continuously refine existing knowledge on the development of energy markets, about regulated monopolies, and about their interaction. This includes issues such as how legal frameworks should be formulated, how roles and responsibilities in the energy sector should be structured, and how regulatory frameworks affect both network companies and the companies that participate in the deregulated part of the electricity market. As energy markets in the Nordic region and the EU are harmonized, this kind of research is extremely relevant for the transition towards a sustainable energy system.

For example, it is expected that a transition to a sustainable energy system will require that electricity customers play a more active role in markets for electricity and ancillary services but at present there is little knowledge about potential new commercial arrangements.

The Inspectorate therefore suggests that:

Existing mechanisms should be used to finance research, development, and demonstration projects. However, the Energy Markets Inspectorate should be given an increased role in the distribution of resources and resources to develop new electricity market designs and regulatory frameworks.

Finally, it is important that decisions to finance research, development, or demonstration projects follow the national action plan described in Section 8.3.

8.3 An action plan for adapting the electricity networks

There is no common view among the stakeholders on what the Swedish electricity networks will look like in the future. The lack of a common view concerns all levels of the network - trunk transmission, regional, and local. Several network companies, especially the smaller ones, have asked for guidance on how to make the appropriate investment decisions when modernising their grids. Furthermore, there is no shared view on the future of the electricity grid either within or between some of the larger network companies. A shared view among network companies and other stakeholders is required if research, development, and demonstration projects are to be coordinated and controlled in an effective manner. But there are as yet no concrete research and development results that could be used to formulate such a common view.

The Inspectorate therefore suggests that:

The Swedish transmission system operator, Svenska Kraftnät, is commissioned to develop a national action plan that outlines the actions required to obtain an electricity network that is adapted to achieving the political aims for renewable electricity generation and the transition to a sustainable energy system. An important prerequisite for the action plan is that it includes a mechanism to socialize the grid development costs that arise when wind power and other renewable electricity generation is connected to the grid.

The plan should cover all three levels of the grid (trunk transmission, regional and local) and take into consideration the roles played by different stakeholders including network companies, small and large electricity generators, electricity suppliers, and large and small consumers.

8.4 Incentives for smart grid investments

Network companies are regulated local monopolies. Starting in 2012, a new model for network regulation that determines ex ante the allowed revenues of network companies will be implemented. The Inspectorate is of the opinion that the design of the regulatory framework does not represent a serious barrier to smart grid deployment by network companies.

Even though the new regulatory framework gives the network companies room for investment, it does not encourage them to invest in the technologies needed to facilitate the transition to a sustainable energy system. This is a consequence of the uncertainties arising from untested technologies. The regulatory framework does only gives weak incentives for network companies to seek out innovative solutions, even though these solutions could support new arrangements and could, longer term, prove more effective in delivering a sustainable energy system.

The Inspectorate has therefore analysed the possibilities to create, within the coming regulatory framework, extra incentives to encourage network companies to seek out such solutions. The Inspectorate has come to the conclusion that this can be done within the context of the existing quality incentive mechanism.
The Inspectorate therefore proposes:

Additional incentives for network companies to invest in smart grids are added to the regulatory framework.

There are a few points that should be kept in mind concerning quality incentives. There is a risk that an incentive programme that is introduced before suitable and well-tested technology for smart grids is available on the market will lead to excessive investments in conventional solutions. It is therefore important that suitable quality measures are defined in conjunction with developments in technology and taking into account the possibility of new services, as well as the maturity of the solutions. Concrete suggestions for suitable quality measures have been suggested by both ERGEG and by a number of European network companies through the European Electricity Grid Initiative. However, the Inspectorate is of the opinion that at present, it is too early to add any of these quality measures to the incentives mechanism. Further development of smart grid technologies will be required, as a prematurely launched incentive mechanism based on poorly defined quality measures will not speed up smart grid adoption - instead it might lead to the opposite - excessive investments in conventional solutions.

The Inspectorate therefore intends to launch an incentives-based mechanism only during the second regulatory period that will run from 2016 to 2019. By then, the Inspectorate will have developed suitable quality measures and a quality model that will provide network companies with additional incentive to invest in smart grids. The quality measures will be thought to enable network companies to deliver the electricity network required for a sustainable energy system by encouraging them towards "new" and more complex services or improved network performance.

8.5 Hourly metering for the majority of customers

The Swedish government commissioned the Inspectorate to examine whether it is feasible to extend hourly metering to a larger set of electricity customers than today. The Inspectorate presented its finding in the report "Ökat inflytande för kunderna på elmarknaden"[139] ("Increased customer influence on electricity markets") which was delivered to the Government on November 25th 2010. In the report, the Inspectorate proposes that all electricity customers with an annual consumption of 8 000 kWh or more should be hourly measured.

This conclusion is compatible with the findings in this report. The network tariffs that are most likely to give customers the right incentives to shift demand from peak periods to off-peak periods are those that require hourly meter reading.

8.6 Review of network tariff structures to reduce peak load

The Electricity Law gives network companies considerable freedom in how they charge customers. As long as tariffs are objective and non-discriminatory, network companies are free to design their own tariffs. Other than regulating the revenue network companies are allowed to recover from their customers, the Inspectorate has little influence over the way tariffs are structured.

In this report, the Inspectorate has pointed out that a reduction of local load peaks can facilitate the integration of increased electricity generation from renewable energy sources and the future electrification of the transport sector.

The structure of a network tariff can have a strong influence on the load and consumption patterns of individual customers. Use of network tariffs can be designed so as to influence the behaviour of both customers and network

[139] EI R2010:22

companies and suitably designed network tariffs can help reduce peak loads and the need for grid infrastructure investments.

Against this background, the Inspectorate suggests that:

The Inspectorate shall be commissioned to review the structure of network tariffs with the aim to reducing load peaks.

8.7 Functional requirements for information to enable customers to react to price signals

The Inspectorate has also been commissioned by the government to investigate hourly metering, billing of small electricity customers, and net metering for small-scale generation.

Smart metering is often viewed as integral to the smart grid. However, there is currently not enough knowledge about the way in which the functionality that is attributed to smart metering in the technical literature can be used to facilitate the transformation of the Swedish electricity network to support a sustainable energy system.

Internationally, there is considerable ongoing work to define minimum functional requirements for smart metering. The EU is expected to deliver clearer requirements, either as a complement to existing standards or as a new set of standards.

The Inspectorate is of the opinion that Sweden should only introduce those minimum functional requirements related to hourly meter reading, net metering, and customer access to metering. Additional minimum functional requirements should not be considered at the present time. Sweden should not introduce any more minimum functional requirements until the various European initiatives to develop minimum functional requirements for smart metering have presented their results.

Electricity customers will be able to respond to price signals if hourly metering is introduced, and if network tariffs and electricity tariffs are properly designed. Against this background, the Inspectorate proposes that:

The Inspectorate shall be commissioned to formulate functional requirements for the information that is provided to electricity customers, the purpose of which being to increase their chances to actively respond to the electricity market's price signals.

8.8 Analysis of the roles and responsibilities of various actors

The electricity market is divided into a regulated network part and a deregulated part where electricity is traded. The Energy Markets Inspectorate is responsible for monitoring the activities of the regulated network companies, and to make sure that there are no cross-subsidies between regulated and non-regulated divisions within conglomerates.

The strict requirements on separation of electricity transport activities from generation, production and supply following unbundling restricts the ability of network companies to cooperate with companies that are active in the deregulated market. However, collaborative efforts may be necessary to support the transition towards a sustainable energy system. Cooperation is needed in areas such as research, development, the execution of demonstration projects, as well as the sharing of knowledge and experience. Network companies and companies operating in the deregulated market might profit from jointly financing projects that yield benefits for multiple stakeholders.

It is important that structural barriers do not hinder valuable collaborative efforts that can speed up smart grid adoption. It is also important that structural barriers do not hinder collaborative efforts to establish new market actors that provide new services made possible by the smart grid. Finally it is important that the legal restrictions do not hinder network companies from carrying out activities that cannot easily be classified as either being regulated or deregulated and that help them operate their grids in a more effective manner. It is therefore important that this legal issue is analysed further so that the electricity market can be adapted to changing technical circumstances. Any modification of the regulatory framework governing the entire electricity market must of course take existing EU law into account.

Against this background, the Inspectorate proposes that:

The Inspectorate is commissioned to examine the roles and responsibilities of the various stakeholders in the electricity market, with the aim to identifying and proposing measures to promote the use and development of smart grids.

8.9 Trunk transmission, regional, and local networks

The Swedish electricity grid is currently split into three levels: local distribution networks, regional networks, and the national (trunk) transmission grid, the "backbone" of the grid. Under this division, transmission takes place at two levels, regional and national. This distinction may act as a barrier to an efficient usage of the grid.

The regional transmission grid operates at voltage levels between 20 kV and 130 kV. The existence of this level creates uncertainty over where the line between distribution and transmission should be drawn. This uncertainty is also deemed to be an obstacle to the connection of wind power since it makes it more complicated to find financing for efforts to connect wind power to the grid.

A modification of the current split into three levels should therefore be considered. Higher voltage levels in distribution grids would also make it easier to plan for the connection of renewable electricity generation plants to the grid.

Against this background, the Inspectorate proposes that:

The Inspectorate is commissioned to examine whether the current division of the grid into three levels is appropriate.

8.10 Schedule for implementing the proposals

The four-year regulatory periods must be taken into account when plans are made for when the proposals described in this chapter should be implemented. The first regulatory period runs from 2012 to 2015. Network companies must send in their proposals for revenue allowance by March 2011, and the Inspectorate assesses them and reaches a decision by Autumn of 2011. The second regulatory period runs between 2016 and 2019. Network companies must hand in their proposals for revenue allowance by March 2015.

The results of the various studies, national action plan and other activities proposed in this report should therefore be available well before March 2015 so that network companies are given sufficient time to adjust their investment plans for the 2016-2019 regulatory period.

8.11 High level impact analysis

This report has presented a number of proposals designed to deliver the electricity networks required for a sustainable energy system. If these proposals are not carried out, there will be two main costs. The cost of using traditional measures such as the construction of new power plants and new grid lines to reach the political goals (a sustainable energy system) will most likely exceed the cost of using smart grid technologies. Furthermore, the transition to a sustainable energy system using conventional solutions will most likely take more time than had smart grid solutions been used. Such a delay will make it much more difficult to reach the goal of a sustainable energy system.

8.11.1 Costs for the state

The creation of a knowledge platform managed by an independent council will require the establishment of a new organization. This organization is expected to require the equivalent of two full time positions. According to the proposal the council will not have own funds that it can distribute to research, development, and demonstration projects. The council will only have a coordinating role, and the decisions on which projects to sponsor will be taken by existing organizations. The council is responsible for making sure that the electricity grid research area is given the priority that is required to make smart grids a reality.

8.11.2 Costs for the Transmission System Operator

Svenska Kraftnät has been proposed as the party that will be responsible for developing the national action plan for smart grids. Many of the proposed technical changes for the grid as a whole are already a reality in the central transmission grid that is managed by Svenska Kraftnät. Svenska Kraftnät would have to suggest how these high voltage procedures can be applied at lower voltage levels as well. It is expected that Svenska Kraftnät will be able to handle this new mission within its existing budget.

8.11.3 Costs for the Energy Markets Inspectorate

There is a proposal that the Inspectorate should be given increased possibilities to influence the way research funds are distributed. The Inspectorate should also be given increased possibilities to finance research into market designs and regulatory frameworks. The Inspectorate believes that these two new tasks can be easily integrated into its normal activities. However, it also believes that the two tasks need to be formalized. The purpose of this proposal is to prioritize research related to electricity grids and electricity markets.

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