TAMPEREEN TEKNILLINEN YLIOPISTO
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EMMI SAARINEN

HOME ENERGY MANAGEMENT SYSTEM IN ENABLING POWER BASED NETWORK TARIFF

Master of Science Thesis

Examiners: Professor Risto Raiko,
Professor Pertti Järventausta
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ABSTRACT

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EU has set new Energy Efficiency Directive which will affect to the electricity distribution business. There will also be some significant changes in the electricity market that will affect to the future tariff structure. Energy efficiency, small-scale energy production, energy storages and distributed generation will reduce the amount of transferred energy. However, these changes do not reduce the peak power considerably. Consequently, the revenue of the distribution system operators (DSOs) will decrease if the tariff structure does not change because in current tariff structure energy-based fee still forms the majority of the DSO's revenue.

Power based power band tariff is considered one of the best options for the future network tariff. The goal of the power band is to decrease the peak power level. That would relieve the stress on the distribution network and also temporarily postpone the need for network renovation. Home Energy Management System, HEMS, is a system that enables the user to control and optimize the electricity consumption. In the work, HEMS was piloted in co-operation with a service provider company There Corporation and a new steering algorithm was developed. The steering algorithm is based on the controllable loads that can be steered to switch off when the total power consumption of the household increases. The goal was to investigate whether the HEMS combined with the steering algorithm is able to allow smaller band sizes for the customers. However, finding the controllable loads for the steering algorithm was quite difficult. Customers had quite positive attitude towards the controlling of heating loads, but there were still some technical challenges. All controllable loads that were used in the pilot were direct electric heating loads. The feedback was collected during the pilot study from the pilot customers.

The use of the power band steering algorithm was piloted successfully. It was seen that the peak powers reduced as well as the overall power level of those customers that had controllable heating loads in the steering algorithm. The average load control potential of the pilot customers varied from 0 to 1,7 kW. The largest decrease in daily peak power was 1,2 kW. However, the steering of the controllable loads enabled relatively small savings for the DSO compared to the investment costs and some of the monetary savings could be achieved only locally. The overall user experience of the steering algorithm was quite positive and the comfort of living was not suffering. The power band tariff must be investigated further before it can be introduced to customers. Also the operation model of the demand response must be developed in cooperation of all parties, meaning DSO, supplier and HEMS provider.

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Euroopan Unioni on asettanut uuden Energiatehokkuusdirektiivin, joka tulee vaikuttamaan jakeluverkkoyhtiöiden toimintaan. Sähkömarkkinoilla tulee lähitulevaisuudessa tapahtumaan myös muita muutoksia, jotka vaikuttavat tulevaisuuden sähkönsiirtotariffeihin. Energiatehokkuus, asiakkaiden oma pientuotanto, energiavarastot ja hajautettu tuotanto tulevat vähentämään siirretyn energian määrää pienentämättä kuitenkaan siirtoverkon tehotasoa merkittävästi. Tämän seurauksena jakeluverkkoyhtiöiden tulot tulevat pienentymään mikäli tariffirakennetta ei muuteta, sillä nykyisessä tariffirakenteessa energiaperusteinen hinnoittelu muodostaa suurimman osan siirtomaksusta.

Tehoperusteista tehokaistaa pidetään yhtenä lupaavimmista tulevaisuuden siirtotariffimalleista. Tehokaistan tavoitteena on laskea siirtoverkon huipputehoa, mikä pienentäisi verkon kuormitusta ja lykkäisi verkon kunnostus- ja uudistustarpeita. Kodin energianhallintajärjestelmä, HEMS, mahdollistaa asiakkaiden energiankulutuksen seuraamisen ja hallinnan kotitalouksissa. Tämän työn aikana HEMS-ratkaisu ja uusi tehokaistaa tukeva ohjausalgoritmi kehitettiin yhteistyössä palveluntarjoajayrityksen, There Corporationin, kanssa. Pilottiin osallistui viisi yksityistä kotitaloutta. Ohjausalgoritmi perustuu ohjattaviin kuormiin, jotka voidaan kytkeä pois päältä asiakkaan kokonaistehon noustessa. Pilottitutkimuksen tavoitteena oli tutkia mahdollistaako ohjausalgoritmilla varustettu HEMS-järjestelmä pienemmän tehokaistan asiakkaalle. Ohjattavien kuormien löytäminen kotitalouksista oli kuitenkin haasteellista ja kaikki käytössä olleet kuormat olivat suoria sähkölämmityskuormia.

Ohjausalgoritmin käyttö pilotoitiin onnistuneesti ja asiakkaat, joilla oli ohjattavia kuormia, saavuttivat pienempiä huipputehoja. Keskimääräinen kuormanohjauspotentiaali vaihteli 0 kW:sta 1,7 kW:iin. Suurin pudotus asiakkaiden tuntitason huipputehossa oli 1,2 kW:a. Jakeluverkkoyhtiö voi hyödyntää pienentyneitä huipputehoja ja kuormanohjausta muun muassa sähköverkon mitoituksessa ja häviösähkön hankinnassa. Tutkimuksessa esitetyt laskennalliset säästöt ovat kuitenkin melko pieniä suhteessa HEMS:n investointikustannuksiin, ja rahallisia säästöjä voitaisiin saavuttaa vain paikallisesti. Asiakkaiden palaute ohjausalgoritmista oli kaiken kaikkiaan hyvin positiivista eikä asumismukavuuden koettu alentuneen tutkimuksen aikana merkittävästi.

Tehokaistaa on tutkittava vielä lisää ennen kuin se voidaan ottaa käyttöön asiakkailla. Myös kysyntäjoustoon liittyvä toimintamalli pitää ratkaista eri toimijoiden kesken ennen kuin kysyntäjoustoa voidaan hyödyntää suuremmassa mittakaavassa.

PREFACE

The topic for this thesis was provided by Elenia Verkko Oy as a part of SGEM (Smart Grids and Energy Markets) research program. During this work Elenia Verkko Oy fused to Elenia Oy, but as a great majority of this thesis work was made under the name Elenia Verkko Oy, this is used later in this work. The examiners for this thesis were Professor Risto Raiko and Professor Pertti Järventausta from Tampere University of Technology. Supervisor from Elenia Verkko Oy was M.Sc. Matti Halkilahti.

I wish to thank Matti for providing me such an interesting and current topic as well as support during the work. I want to thank Risto and Pertti for good advice and for examining this thesis. In addition, I want to thank the employees of There Corporation for the rewarding co-operation during this work.

Above all, I want to express my sincere gratitude for my family for the support and encouragement they have given me. I also want to thank my friends for the memorable moments during the studies.

Kiitos!

Tampere, January 28th, 2013

Emmi Saarinen

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ABBREVIATIONS AND NOTATION

ACER	Agency for the Cooperation of Energy Regulators
CCT	Carbon Capture and Storage
CFL	Compact Fluorescent Lamp
CPP	Critical Peak Pricing
DR	Demand Response
DSO	Distribution System Operator
DEA	Data Envelop Analysis
EEP	Energy Efficiency Plan
ETS	Emmissions Trading System
EU	European Union
HEMS	Home Energy Management System
Ltd.	Limited Liability Company
LUT	Lappeenranta University of Technology
NordREG	Nordig Regulators
SES	Smart Energy Switch
SFA	Stochastic Frontier Analysis
ToU	Time of Use -Tariff
TSO	Transmission System Operator
TUT	Tampere University of Technology
VAT	Value Added Tax

1 INTRODUCTION

Elenia Verkko Oy is responsible of electricity network services for over 400 000 consumers in Finland. Elenia owns and operates distribution networks in one hundred local districts in Kanta-Häme and Päijät-Häme, Pirkanmaa, Central Finland and Ostrobothnia. Company develops and maintains the network according to consumers' needs and secures the good quality of the electricity supply. As a pioneer in smart electricity networks, Elenia has integrated power distribution and data systems into a comprehensive smart electricity distribution grid that provides and applies information in real time. Following a major enterprise sale completed in January 2012, the electricity distribution operation formerly provided by Vattenfall Verkko Oy has now passed to Elenia Verkko Oy. LNI Verkko Oy was an interim name used during the transition period. During this work Elenia Verkko Oy fused to Elenia Oy, but as a great majority of this thesis work was made under the name Elenia Verkko Oy, this is used later in this work. The aim of this work was to pilot a new power based network tariff in which the power level is tried to keep as even as possible. Also a steering algorithm of Home Energy Management System was introduced. The purpose of the steering algorithm was to help the customers to reduce the power level and especially the power peaks.

Electricity distribution has remained natural monopoly position in its operating area, whereas electricity trade and production are free business. Because of the monopoly position, distribution system operators (DSOs) are highly regulated. In Finland the regulator is Energy Market Authority. The pricing of the electricity distribution is controlled over a time periods. Third regulation period started at the beginning of 2012 and it will end on December 2015. The central legislation concerning the electricity distribution business is presented in Chapter 2.

Also a general description of the branch and its future megatrends is provided in Chapter 2. Electricity market has been changing rapidly and will continue to change in the near future. Energy Market Authority has determined four megatrends having the biggest impact on the development of electricity network operations in Finland in the 2010s. These trends suspect that investment need in electricity network increases, dependence on electricity grows, emission-free electricity generation increases and regulation increases and becomes 'Europeanized'. As the regulation becomes more international, there are some amendments to legislation under preparation on the international scale introduced. One of the most important market trends under preparation is the Nordic retail market integration.

Energy has been in a central role during the integration of Europe. The necessity of a common European energy policy is justified by the need to react the new challenges in energy sector concerning climate change, reliability of energy delivery and competitiveness of the European Union. EU has set a series of ambitious climate and energy targets to be met by 2020, known as the "20-20-20" targets. The most important tool for meeting these targets is Energy Efficiency Directive. The European Commission gave a proposal of Energy Efficiency Directive in June 2011. A lot of debate on the proposal was going on before the directive was finally agreed by the European Parliament and Council in June 2012. The Directive will affect to the companies in energy sector as well as electricity distribution business, by setting them requirements but also enabling new business opportunities. The most significant parts of the Energy Efficiency Directive are introduced in Chapter 3. Also the effects of the improved energy efficiency on the electricity distribution business are provided in this chapter.

In Chapter 4 principles of electricity pricing and the formation of current tariff structure are introduced. In the future, there will be some significant changes in the electricity market that will affect to the future tariff structure. Energy efficiency, energy saving actions, energy storages and distributed generation will reduce the amount of transferred energy. However, these changes do not reduce the peak power considerably. Consequently, the revenue of the DSOs will decrease if the tariff structure does not change because in the current tariff structure energy-based fee still forms the majority of the DSO's revenue. These changes in the operational environment drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level. The development of metering devices and load control possibilities will support and bring new possibilities to the new tariff structure. The future network tariff structure should enable the demand response (DR) in a way that also the DSO would benefit from it. Demand response means shifting the power demand away from the peak power hours. Also other requirements for the new tariff structure are provided and potential network tariffs introduced. Power based power band tariff is considered one of the best options for the future network tariff and therefore introduced in more detail.

Power band is a distribution pricing scheme developed from power based pricing. The concept of power band is familiar to the public through internet broadband. Partanen (Partanen et al. 2012) determines the power band as follows; in the context of electricity distribution, the concept would mean that a customer would subscribe to the desired subscribed power, in other words, electricity distribution capacity, provided by the DSO. A customer's power band would be determined based on the highest metered hourly mean power of the year. The goal of the power band is to decrease the peak power level. That would relieve the stress on the distribution network and also temporarily postpone the need for network renovation. Power band has also positive energy efficiency impacts on the national level.

Home energy management system, HEMS, could help customers to achieve lower peak powers. HEMS is a system that enables the user to control and optimize the electricity consumption in a cost-effective way. HEMS includes additional home automation that enables the steering and the monitoring of device-specific electricity consumption. One major objective of this study was to evaluate how HEMS supports power band tariff in households. In the work, HEMS was piloted in co-operation with a service provider company There Corporation and a new steering algorithm was developed. The goal was to investigate whether the HEMS combined with the steering algorithm is able to allow smaller band sizes for the customers, and also identify potential technical obstacles. The feedback was collected during the pilot study from the pilot customers. The pilot study is discussed in Chapter 5.

Evaluation of the HEMS-solution and power band is provided in Chapter 6. Customer feedback and collected metering data were used to evaluate the benefits of the HEMS-concept from both customer's and DSO's point of view. It was investigated how the HEMS could be utilized in power band scheme and if the steering algorithm enabled smaller power band size for the customers. Next, potential benefits for the DSO were analyzed. The goal of the power band is to decrease the peak power level which would eventually relieve the stress on the power grid and also temporarily postpone the need for network renovation. It was analyzed whether the algorithm could help to achieve this target. Also analysis was made on how the load control could benefit the DSO in purchasing of network losses. In addition, in the end of the chapter the operation models are discussed from different perspectives. HEMS is a service that enables the DR, and the question is how all the HEMS related operations are divided between the actors. The roles of different actors must be solved before the DR of household customers can be utilized on a large-scale.

2 THE ELECTRICITY DISTRIBUTION BUSINESS

Electricity market includes electricity production, exchange, transmission, distribution and retail. The companies operating distribution networks are called distribution system operators. In Finland the reform of electricity market started in 1995 when electricity market was opened for competition. This included electricity production and retail. In practice, all electricity users were able to choose their electricity supplier not until 1998. Because of this change, distribution networks can now be seen as a market place. (Partanen et al. 2011)

In order to enable full retail market opening and competition, there was an amendment made for the Electricity Market Act (386/1995) stating that electricity distribution operations must have been separated from production and supply since 2007. Distribution operations must be unbundled from other trade operations in the books of the electricity company. This tries to support active competition in electricity production and trade and to remove unnecessary regulation as well as to ensure that profits from electricity distribution, which is in position of natural monopoly, are not used in sectors of the market where competition is possible. The DSO is also responsible for publicizing data on the company's pricing principles, economy and efficiency in order to achieve transparency. (Energy Market Authority 2012a)

Electricity production and trade are free business and do not need a concession whereas electricity distribution has remained its natural monopoly in its operating area. In addition, it requires a network license. The local monopoly status remains because it is neither economically profitable nor sensible to build and maintain parallel distribution networks. Companies are potentially less efficient and do not have incentive for reasonable pricing when in monopoly position. There are also less innovations and investments then. (Energy Market Authority 2012b) Because of this, DSOs are highly regulated. In Finland this regulator is Energy Market Authority.

In this chapter the reader is introduced to some typical characters of network business and future megatrends having the biggest impact on the development of electricity network operations. There are also provided amendments to legislation under preparation on the international scale discussed and some basic information about the legislation and regulation in Finland.

2.1 General description of the branch and its future megatrends

As the distribution network forms the place of electricity market, the DSOs have many duties to make the market functioning. The network license defines the geographical area of responsibility where DSO has an exclusive right to construct distribution networks. In this area, the DSO must transmit electricity and connect to its network electricity consumption sites and power generation. In addition, DSO has an obligation to develop and maintain the power network according to consumers' needs and secure the good quality of the electricity supply. The price of network services must be reasonable and not depend on where within the network operator's area of responsibility the customer is located geographically. (Energy Market Authority 2012c)

Regional electricity companies were municipal corporations before and their main role was to offer services to local residents, not to gain profit. Today, majority of the DSOs are Limited Liability Companies (Ltd.) and owned often by the communes. The overall business objective of a DSO depends highly on the ownership basis. There are some owners whose goal is to produce the greatest possible outcome. Although, many DSOs do not take the maximum profit they would be allowed to. (Partanen et al. 2011)

Network companies focus more on their core business processes and usage of purchased services has been increased in the past years. Network planning, strategic network planning, business planning and customer relationship management can be seen as a core business and are done inside the network company, whereas network construction and maintenance services are the most common purchased services. According to Aminoff et al. (2009) the most popular goals of purchased services, besides cost savings, are interests of focusing on core business and getting additional workforce.

One typical feature of network business is the major role of information systems. Information systems and data management are in a central part of today's network business. DSOs are forerunners when it comes to utilizing information technology in developing their operation. Network companies use many different information systems and integrating them can be problematic. Therefore, the role of information systems is critical when considering the interfaces of the companies in the network business. This is one major challenge when using purchased services and designing new services. Integrating information systems can cause challenges also when different market actors are providing HEMS solutions. (Aminoff et al. 2009)

Electricity market has been changing rapidly and will continue to change in the near future. The main reasons contributing and hastening these changes are electricity market legislation both in national and EU-level, development of DSOs' regulation and changes in consumers' demand. (Partanen et al. 2011) In Roadmap 2020 Final Report (Energy Market Authority 2011a) Energy Market Authority has determined four megatrends having the biggest impact on the development of electricity network operations in Finland in the 2010s. These trends suspect that investment need in electricity network increases, dependence on electricity grows, emission-free electricity generation increases and regulation increases and becomes 'Europeanized'. In addition to these megatrends, there are some other development trends that may contribute to network operations such as introduction of smart grids. In the following, these four megatrends are discussed separately.

The electricity distribution network in Finland was built mainly in 1960s to 1980s, and therefore the majority of the network needs refurbishment or replacement in the next decade. This results in a significant increase in replacement investments in euros. It is important to find the substitutive solutions that would best serve the electricity network to be renovated, as well as its users. Smart grids have an important role in improving the cost-effectiveness of replacement investments. One major investment that was made during the past few years was remotely read hourly metering. (Energy Market Authority 2011a)

In the future, electricity will be used in a more diverse and extensive way in the society. Consequently, the requirements for the security of electricity supply will increase because, in practice, all operations are suspended for the duration of power cuts. In addition, the quality of electricity will be more important because new electrical appliances may be disturbed by even small voltage variations. The customers of the DSOs will become more dependent on undisturbed supply of electricity than before. (Energy Market Authority 2011a)

It is predicted that exceptional meteorological phenomena will increase in the future because of the climate change. As a result, widespread power cuts are expected to become more common. Ministry of Employment and the Economy gave a proposal of actions to improve the reliability of electricity supply in March 2012. The amendments introduced in the proposal would obligate the DSOs to improve the reliability of electricity supply significantly from the current level. The most essential obligations of the proposal are maximum time limits for the power cuts. In city plan area the power cut could not last more than 6 hours and in the dispersed settlement area the maximum limit would be 24 hours. DSOs must meet the requirements by the year 2027. 50 % of these requirements must be met by the end of 2019 and 75 % by 2023. The costs of the underground cables are tried to reduce by allowing locating the cables into roadsides. The overhead lines could also be moved from forest to roadsides. Also the standard compensations of long power cuts would increase considerably. (Ministry of Employment and the Economy of Finland 2012)

EU’s energy targets and policies made in the climate and energy strategy mean that electricity generation based on renewable energy sources will increase which means that small-scale distributed electricity generation will be connected to the electricity networks. As a result, DSOs will have to make investments in the network and increase its intelligence. Two-way electricity transmission will increase meaning that original consumption sites can sometimes show in the network as a production plant feeding electricity to the network. In addition, a significant increase in wind power capacity also means an increase in unpredicted electricity generation in the network. The change in the use of the network requires smart grid. (Energy Market Authority 2011a)

Detailed steering and regulation of network operations at the EU level will increase significantly. At the same time, there will be new national regulations to have an impact on electricity network operations as well. A new EU agency, ACER, has been established for the regulation of Europe-wide electricity network operations. In future, regulation will take place at the national and the European level. Moreover, political decisions concerning renewable energy sources and energy efficiency are made in the EU and at the national level, and as a result, new obligations are imposed on electricity network operations, diminishing the DSOs' independent freedom of action. (Energy Market Authority 2011a)

2.2 Amendments to legislation under preparation on the international scale

As the regulation becomes more international, there are some amendments to legislation under preparation on the international scale introduced next, and their impact on network operations and implementation schedules discussed.

The third legislative package for an internal energy market in the EU was adopted on July 2009 (713/2009). The package includes a partly reformed electricity directive, a partly reformed regulation on the electricity trade, and a completely new regulation on establishing an Agency for the Cooperation of Energy Regulators, ACER. The main issues discussed in the internal market package are transferring the preparation of market rules to the Community level, establishing an agency for the co-operation of energy regulators, structural unbundling between transmission and production/distribution and improving consumer protection in the retail market. (European Commission 2012)

One significant new element of the package is the Europeanization of the electricity market regulation. National freedom of action will narrow as the rules on the electricity market and electricity trade will be developed at the European level increasingly. The new EU-level rules will mainly have an effect on the transmission system operator. As for the DSOs, the most significant impact of the third directive package is the unbundling of transmission networks. Unbundling should prevent network operators from favoring their own energy production and supply companies. In practice, at least legally unbundled DSOs are required to differentiate more transparently than before their operations and communications from the part of enterprise that carries on sales and production operations. This applies especially to communications and brands. (European Commission 2012)

In November 2010, the European Commission published its new strategy 'Energy 2020 – A strategy for competitive, sustainable and secure energy.' It defines the energy priorities for the next ten years and sets the actions to be taken in order to achieve the goals of saving energy, achieve a market with competitive prices and secure supplies, boost Europe's technological leadership, and effectively negotiate with international partners. The main five priorities are:

- Energy saving
- A pan-European integrated energy market and its infrastructure
- A common voice in energy issues
- Europe's leadership in energy technology and innovation

- Safe, secure and reasonably priced energy supplies by empowering consumers

The most significant target that concerns network operations is the building of a pan-European integrated energy market and its infrastructure. (European Commission 2010a)

The European commission also presented its energy infrastructure priorities for the next two decades in November 2010. The aim of this is to make the networks fit for the 21st century. The Commission has defined four EU projects and the one having impacts on Finland is the integration of the Baltic energy market into the European market. The project aims to integrate the Baltic countries more closely in to the European electricity markets by upgrading the internal electricity networks in these countries and by strengthening connections to Finland, Sweden and Poland. (Energy Market Authority 2011a)

2.3 The common Nordic end-user market

One of the most significant market trends under preparation is the Nordic retail market integration. The Nordic energy regulators (NordREG) have been working for several years towards developing a common Nordic electricity retail market, which means that a single consumer could freely choose the electricity supplier in the Nordic area. NordREG published an implementation plan for a common Nordic retail market in 2010. The common Nordic retail market is estimated to be operational by the target year of 2015, but the target year is not absolute. The target of the integration is to facilitate smooth retail operations by electricity suppliers with an ambition to operate in all Nordic countries. Consumers and other small-scale users of electricity would have a better opportunity for active participation in the Nordic electricity market. They are expected to benefit from the expanding and more specialized product selection and increased competition. This will steer actors to improve the efficiency of their operations. New actors are also expected to enter the market. (Energy Market Authority 2011a)

There are three sectors in a central role in the common Nordic retail market model; customer interface model, balance determination model and data exchange model between market actors. NordREG (NordREG 2010) proposes that the new market would base on a supplier-centric customer interface model where the supplier would be the primary contact point for the customer in issues such supplier switching, moving and electricity consumption. Issues concerning the physical network like electricity connection would be still handled with the DSO so it is not a pure single point contact model, but in principle a dual point of contact-model. This is quite similar to the dual-point of contact-model used currently in Finland.

One major issue in the customer interface is arranging customer billing. In Finland and in other Nordic countries, a customer who has switched his electricity supplier usually receives a separate bill for electric energy and electricity distribution. It is recommended that combined billing would be the most suitable billing regime for the Nordic end-user market in the future. (Lewis 2011) Combined billing means that companies that sell electricity would also handle the billing for customers' electric energy and transmission on a single bill. At the same time they collect all other fees such as relevant taxes and duties. However, the Ministry of Employment and the Economy of Finland have stated in recent comments that it does not support the combined billing. They see that cons outweigh the positive aspects in the transition to the combined billing. The Ministry justifies its opinion by saying that DSO's contact to the customers cannot become weaker, price of the new information system is too big considering customer's benefits and possibilities of small market actors must secure. Other Nordic Countries still support the combined billing. (Finnish Energy Industries 2012a) In addition, transferring to a common Nordic retail market means changes in the balance determination model and in data exchange model between market actors. A new common balance determination model is under preparation and intended to introduce by the year 2015.

2.4 Legislation in Finland

The ministry of Employment and the Economy has the overall responsibility to regulate the energy industry in Finland. Ministry is responsible for operating conditions of enterprises, securing the consumers position in the market and taking care of the public enterprise property. There are three main goals in the Finland's current energy policy: well-functioning energy market, securing the energy supply and limiting emissions determined by the international laws. It is not considered likely that these targets would be met without regulation, and that is why the regulation of different authorities is needed. (Finnish Energy Industries 2012b)

Electricity distribution is under the supervising of Energy Market Authority, Finnish Competition Authority, Consumer Agency and Finnish Safety and Chemicals Agency. Energy Market Authority monitors the observance of Electricity Market Act and the obligations that are assigned to the DSOs by the Act. It also works for improving the overall functionality of the electricity market and regulates the electricity distribution business by setting a limit for the maximum profit of a DSO. As discussed earlier, the role of the European Union has become more significant in steering the energy policy and will continue to do so. (Finnish Energy Industry 2012b)

2.4.1 Regulation

Regulation of the electricity distribution business aims for reasonable pricing, cost effective operations and evenhanded dealing with customers. In Finland the electricity distribution has been regulated under the Electricity Market Act (386/1995) since 1995. At the beginning the regulation was not very active and only in 1999 a proper regulation model was developed. The calculated profit of a company was compared to the reasonable profit calculated based on the capital committed to distribution business. If it was proved that the pricing of the electricity had not been reasonable, the company was urged to make the pricing more reasonable in the future. Until the end of 2004 the regulation was made only afterwards. (Partanen et al. 2011)

In 2001 the performance measurement was introduced. It tried to encourage cost-effective operations by setting a target level for operational costs. However, this regulation method did not work as well as expected and the applying of results was problematic because companies knew only after the control period what was the level of the operational costs they should have reached. (Partanen et al. 2011)

Regulation system was reformed in 2005 so that it would meet the needs of the European Parliament’s directive 2003/54/EC and of the Council concerning common rules for the internal market in electricity. Also duration of the regulation period was changed from one year to four years and reasonableness of pricing was regulated in longer periods, not based on a statistics of a one certain year. During the first control period in 2005-2007 limits for reasonable operating costs, depreciation write-offs and capital profits were defined. Also the general efficiency improvement target was set. Second control period in 2008-2011 did not significantly differ from the first one. Only company-specific efficiency improvement target and quality incentive were set. The company specific target was set by using Data Envelop Analysis (DEA) and Stochastic Frontier Analysis (SFA) efficiency evaluation models. (Partanen et al. 2001)

The third control period started on January 2012 and will end on December 2015. Energy Market Authority has used experiences from the previous control periods when developing the new model. The basis of the regulation model remains but there are some improvements made and new incentives introduced. The basic idea of the regulation of reasonable pricing is to determine the level of reasonable return yield and compare this to the actual adjusted incomes of a DSO. The reasonable return yield is calculated by determining the different types of capital and giving them a reasonable rate of return. The investment incentive was added to make sure that DSOs have enough incentives to develop networks and invest enough on it. Also innovation incentive was applied and the level of quality incentive was increased. Energy Market Authority has tried to make the regulation model as logical and clear as possible. (Energy Market Authority 2011b)

2.4.2 Regulation and HEMS

The value of adjusted capital invested in the DSO’s network operations is determined annually. It is used in the calculations to determine the DSO’s reasonable return. When DSOs consider providing new services, such as HEMS solutions, the question is whether the investments are able to include in the adjusted capital invested in network operations.

The electricity network forms the greatest individual part of the DSO’s fixed assets and it is comprised of several different components; electricity lines, substations and other necessary electrical equipment for the purpose of electricity distribution or transmission. In current regulatory period additional equipment, like HEMS, is not possible to include in the adjusted capital invested in network operations. Energy Market Authority states that "Investments in non-current assets are eliminated in connection with the adjustment of the DSO's balance sheet. Investments in non-current assets include, e.g. profit-seeking investments or investments aiming for expansion of business operations. These kinds of investments cannot be regarded as necessary with respect to actual electricity network operations, due to which it is also not justified to include them in any part in the adjusted capital invested in network operations on the basis of which the DSO's reasonable return is formed". Consequently, providing services such as HEMS can be seen as a profit-seeking investment, and thus is not able to include in the adjusted capital invested in network operations in the current control period. (Energy Market Authority 2012b)

2.4.3 Customer billing

Energy Market Act (386/1995) sets accurate requirements about the information that must be provided in the electricity bill. The bill must be clear and easy to understand, but still provide all the information required. The DSO must give to its customer an itemized account of how the price of the system service is formed. There is a detailed list of requirements that must be reported on the bill in the Act.

If the network tariff structure changes to power-based pricing model, it will cause some significant changes to the billing policy. The information provided on the bill must help customers to understand the formation of their tariff fee. It must be explained in detail how the power band tariff is formed and what is the peak power used in determining the band. Bills can also be utilized in providing additional information about the new tariff, for example how to reduce the band size and what kind of equipment for monitoring and limiting the power demand there are available. Also different web-services, like the OnLine-service provided by Elenia Verkko Oy, will improve the customers' understandability by providing the consumption data to customers. As mentioned earlier, the common Nordic end-user market may also affect to the billing by introducing the combined bill in the future.

3 ENERGY EFFICIENCY

Energy efficiency is one of the most cost-effective ways to reduce emissions of greenhouse gases and other pollutants. In many ways, energy efficiency can be seen as Europe's biggest energy resource and it is a key step towards achieving long-term energy and climate goals. (Energy Efficiency Plan 2011) Energy efficiency means using less energy to provide the same or improved level of service, so it does not reduce the comfort. Energy saving is broader concept, including also the reduction of energy production through behavior changes that are short-term, whereas energy efficiency actions are done by using long-lasting technologies.

European Union has set itself an ambitious target for the year 2020 of saving 20% of its primary energy consumption compared to projections. New Energy efficiency Directive will come into force in the beginning of 2014. Hence, national targets and incentives have been set and more is likely to come. In this chapter the main points of the EU’s energy policy are introduced. In addition, the effects of the energy efficiency to electricity distribution business are presented.

3.1 European Union’s energy policy

Energy has been in a central role during the integration of Europe. The necessity of a common European energy policy is justified by the need to react the new challenges in energy sector concerning climate change, reliability of energy delivery and competitiveness of the European Union. Today the European Union has three main goals: sustainable development, maintaining the competitiveness of industry and ensuring the energy supply. These targets are meant to reach by improving energy efficiency, utilizing renewable energy sources and promoting the introduction of new technology. (Finnish Energy Industries 2012c)

Innovations and fast development of new technology are needed to achieve the energy targets. The biggest challenges are related to the development of clean technologies, such as improving energy efficiency and carbon capture technology. Also integrating the transmission grid is one major challenge. Cooperation of many different sectors is in a vital role in achieving the targets. (Finnish Energy Industries 2012c)

3.1.1 The EU climate and energy package

In March 2007 the European Union’s leaders decided to put together distinct climate and energy policy. The aim was to combat climate change and increase the EU’s energy security while strengthening its competitiveness. The EU Heads of State and Government set a series of ambitious climate and energy targets to be met by 2020, known as the "20-20-20" targets. They included three main goals. Greenhouse gas emissions should be reduced at least 20 % below 1990 levels. Secondly, 20 % of the EU's energy consumption should come from renewable resources. And thirdly, a 20 % reduction in primary energy use should be achieved by improving the energy efficiency. This means that in 2020 the primary energy use needs to be 20 % smaller than estimated at the time of setting the target. (European Commission 2010b) As mentioned earlier, the 20-20-20 target is extremely ambitious and Commission's latest estimations suggest that the EU will achieve only half of the 20 % target in 2020.

In January 2008 the European Commission proposed binding legislation to implement these targets. The climate and energy package was agreed by the European Parliament and Council in December 2008 and became a law in June 2009. In the climate and energy package, strengthening of the Emissions Trading System (ETS) is in a key role for cutting emissions cost-effectively. In addition, a legal framework to promote the development and safe use of carbon capture and storage (CCS) is introduced. CCS is a promising group of technologies that capture the carbon dioxide and store it in underground geological formations where it cannot contribute to global warming. The climate and energy package creates pressure to improve energy efficiency but does not address it directly. This is being done through the EU's energy efficiency action plan. (European Commission 2010b)

3.1.2 Energy Efficiency Directive

The European Commission gave a proposal of Energy Efficiency Directive (2012/27/EU) in June 2011. A lot of debate on the proposal has been going on and finally in June 2012 the directive was agreed by the European Parliament and Council. European Parliament has voted for it in the autumn 2012 and it is now agreed officially in the Council and Commission. The Directive is supposed to come into force in the beginning of 2014. This Energy Efficiency Directive is the most important tool for meeting the EU's 20-20-20 target. It will affect to the companies in energy sector as well as electricity distribution business, by setting them requirements but also enabling new business opportunities. (Finnish Energy Industry 2012d), (European Commission 2010b)

The Energy Efficiency Directive is firmly related to the Europe 2020 Strategy for smart, sustainable and inclusive growth, as the EU's 20 % energy efficiency target is part of one of the five headline targets under this Strategy. The Directive overlaps with the scope of two directives: the Cogeneration Directive (2004/8/EC, CHP Directive) and the Energy Services Directive (2006/32/EC, ESD). Both directives have failed to meet the targets of energy saving potential. Therefore, it is proposed that these two Directives are repealed when the new Directive enters into force, except for Articles 4 (1) to (4) and Annexes I, III and IV to the ESD. This provides a more integrated approach to energy efficiency and energy savings. Some administrative simplifications should also result from the need to transpose only one directive instead of two.

Finnish Energy Industries states that the proposal agreed by the European Parliament and Council is better than the original Commission's proposal in many ways, but yet includes many additional obligations to companies in energy sector. The original proposal had many problematic points for energy companies and majority of them has been removed or essentially reduced in the agreed version. Some unclear constructions and a great amount of details are still included, but these things can be clarified on national enforcement. The most significant parts of the Energy Efficiency Directive from the DSO point of view are introduced next briefly. (Finnish Energy Industries 2012d)

Article 6: Energy efficiency obligation schemes

The most challenging part of the new directive is the energy efficiency obligation scheme that each member state must set up. This scheme shall ensure that either all DSOs or all suppliers operating on the member state's territory achieve annual energy savings equal to 1,5% of their energy sales. This amount of energy savings shall be achieved among final customers. The energy efficiency obligation scheme can be replaced by alternative actions which have to be approved by the commission.

Member states are allowed to reduce the annual 1,5 % energy saving target by 25 % the most so that the final target would be approximately 1,1 %. There are four ways to do that:

1) Grading the target annually as follows: 2014–2015 1,0 %, 2016–2017 1,25 % and 2018–2020 1,5 %,
2) Excluding Emission Trade System's energy use from the target,
3) Considering intensification of energy transport and distribution, and
4) Taking into account energy efficiency improving actions done in 2009-2014.

Yet, the target is very challenging to Finland because the most cost-effective actions to improve the energy efficiency are already done. The Ministry of Employment and the Economy has estimated that investments of 300 - 500 millions are needed to reach the target. (Finnish Energy Industries 2012d)

Article 7: Energy audits and energy management systems

Member states shall develop programs to encourage households and small and medium-sized enterprises to undergo energy audits. For large-scale enterprises energy audits are compulsory if company does not have an energy management system consistent with the directive. (Finnish Energy Industries 2012e)

Article 8: Metering and informative billing

Member states shall ensure that final customers for electricity, natural gas, district heating or cooling and district-supplied domestic hot water are provided with individual meters that accurately measure and allow making available their actual energy consumption and providing information on actual time of use. However, member states do not have to apply this section on to district heating and cooling if they can show that using the equipment concerned is not cost-effective.

Article 8 also states that billing must be accurate and based on actual consumption onwards January 2015. This includes energy distributors, distribution system operators and retail energy sales companies. Member states should also ensure that final customers are offered a choice of either electronic or hard copy billing and the possibility of easy access to complementary information allowing detailed self-check on historical consumption. In addition, if requested by final customers, information on their energy billing and historical consumption must be made available to an energy service provider designated by the final customer. (Finnish Energy Industries 2012e)

Article 10: Promotion of efficiency in heating and cooling

Member states shall establish a national heating and cooling plan for developing the potential for the application of high-efficiency cogeneration and efficient district heating and cooling. They shall ensure that when designing new or renovating old electricity generation power stations with a total thermal input exceeding 20 MW, a cost-benefit analysis must be done to evaluate the option of cogeneration. This analysis will be a condition for the environmental license. Also when designing new or renovating old factory with a recovery of waste heat and a total thermal input exceeding 20 MW, a cost-benefit analysis for joining the waste heat to heat demand points is needed. (Finnish Energy Industries 2012e)

Article 12: Energy transmission and distribution

National energy regulatory authorities should consider energy efficiency in their decisions on the operation of the gas and electricity infrastructure. For DSOs the most important content of this article is in the Annex XI, which provides more detailed regulations on network tariffs:

1. Network tariffs shall accurately reflect electricity and cost savings in networks achieved from demand side and demand response measures and distributed generation, including savings from lowering the cost of delivery or of network investment and a more optimal operation of the network.

2. Network regulation and tariffs shall allow network operators to offer system services and system tariffs for demand response measures, demand management and distributed generation on organized electricity markets, in particular:

a) the shifting of the load from peak to off-peak times by final customers taking into account the availability of renewable energy, energy from cogeneration and distributed generation;

b) energy savings from demand response of distributed consumers by integrators;

c) demand reduction from energy efficiency measures undertaken by energy service companies and ESCOs;

d) the connection and dispatch of generation sources at lower voltage levels;

e) the connection of generation sources from closer location to the consumption; and

f) the storage of energy.

For the purposes of this provision the term "organized electricity markets" shall include over-the-counter markets and electricity exchanges for trading energy, capacity, balancing and ancillary services in all timeframes, including forward, day-ahead and intra-day markets.

3. Network tariffs shall be available that support dynamic pricing for demand response measures by final customers, including:

a) time-of-use tariffs;

b) critical peak pricing;

c) real time pricing; and

d) peak time rebates.

In addition, concrete measures and investments for the cost-effective energy efficiency improvements in the network infrastructure must be done, with a detailed timetable for their introduction. This article also sets priority accessing requirements for electricity from high efficiency cogeneration to the grid. (Finnish Energy Industries 2012e)

3.2 Building Code

Approximately 40 % of total energy consumption and carbon dioxide emissions come from housing in Finland and in European Union. That is why it is important to improve the energy efficiency in housing. Energy efficiency of new constructions has been guided with the building code in Finland. New building code came into force in July 2012 and the improvement in energy efficiency is about 20 % compared to the previous legislation. (Ministry of Environment 2011a)

The most essential change is the introduction of a new so called E-number, which determines the overall energy consumption of the building. The aim is to consider the building's energy consumption more comprehensively. The E-number is calculated by using the source of energy used in the building in heating, ventilation, lightning, domestic hot water and appliances. The E-number must be under a certain limit to get the building permit. New building code provides builders more opportunities and variety to achieve the E-number small enough. It is hoped to develop construction business and energy efficiency planning. For example, the E-number of a single-family house with direct electric heating is small enough if there is a fireplace with storage. People are encouraged to use renewable energy sources, such as geothermal heating and pellets. This change prepares the legislation towards the EU's target of zero-energy building. (Ministry of Environment 2011a)

Gaia Consulting Oy (2012) has evaluated the impacts of the new building code. In the figure 3.1 there is a calculated impact of the new building code to the residential and service buildings' energy use build in 2010-2020. It is calculated that the energy used in heating will be approximately 0,9 TWh smaller at that time than the estimated consumption of 6,1 TWh without the impacts of the new building code. This reduction corresponds to 15%. Correspondingly, electricity use will be 0,8 TWh smaller than the estimated 3,5 TWh, which corresponds to 23 %. It is not that easy to evaluate the use of electricity because there are so many factors using it and there will also be other ways to limit the use of electricity, such as EU's minimum energy efficiency levels for different devices. In theory, it would be possible to lower the energy consumption even more with stricter building code.

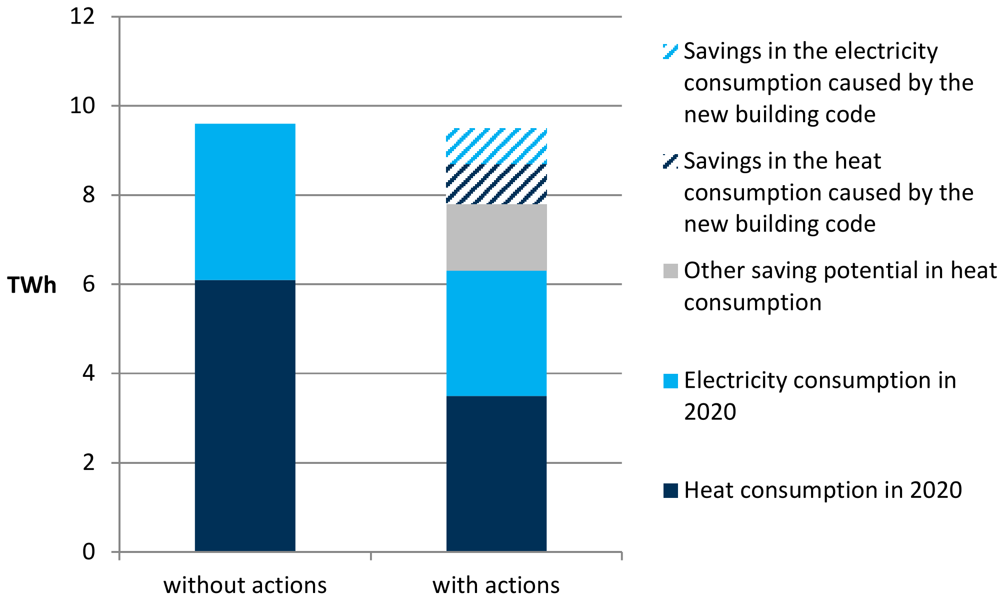

Figure 3.1. *Impact of the new building code to the residential and service buildings' energy use. (Modified from Gaia Consulting Oy 2012)*

The European Union's Energy Efficiency Directive sets the public sector to a forerunner's role in terms of building's energy efficiency. The Directive has set stricter targets to the public sector aiming at zero-energy building by the year 2019. Importance of energy certificates will increase and they will also consider old detached houses in the future. Energy guidance and informative communication are important when improving the energy efficiency among the builders, municipalities and organizations. (Ministry of Environment 2011b)

3.3 The effects of the improved energy efficiency on the electricity distribution business

As the European Union demands more efficient use of energy the electricity market actors must be aware of potential changes in the business environment. For example, in the new Energy Efficiency Directive discussed earlier, all member states are obligated to the energy savings of 1,5 %. Improving energy efficiency will affect both to the energy usage and power demand, which will change the costs and revenue of the electricity distribution business. The effects vary considerably case by case. All actions done to improve the energy efficiency do not necessarily reduce the amount of electricity transferred, whereas the power demand may reduce. The amount of energy transferred affects to the income of the DSO in a short-term (0…5 year) as the power demand in a long-term (10…20). Power demand is the most important factor when dimensioning the grid and planning investments to the grid. (Honkapuro et al. 2010)

Two examples of factors that will change the amount of energy transferred and power demand are heat pumps and electrical vehicles. Also compact fluorescent lamps (CFL), sometimes called energy-saving lights, will have an effect on the electricity and power consumption. The effects of the electrical vehicles to the grid depend greatly on the steering of the charging. If the penetration of the electrical vehicles is large and charging uncontrolled, the power demand in distribution network can increase significantly. This can be avoided by steering the charging smartly when the effect could be meaningless. (Honkapuro et al. 2010) The Ministry of Employment and the Economy of Finland has determined a target level for penetration of the electrical vehicles. It evaluated that 25 % of new cars sold in 2020 are charged from the grid and 40 % of these are full electric cars. (Ministry of Employment and the Economy 2009)

The effects of the heat pumps vary also case by case. If the heat pump is replacing electric heating the energy usage will decrease. On the other hand, if the heat pump is replacing oil heating the electrical energy usage will increase. According to Tuunanen (Tuunanen 2009) heat pumps will decrease the amount of transferred energy by 11 % by the year 2020 whereas the peak power remains the same. This would lead to the reduction of 5 % in the DSO’s yearly revenue. Although heat pumps and other actions affect negatively to the DSO’s revenue, they will help to improve the energy efficiency and that is why should be encouraged to use. These changes drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level.

Customers of the DSOs are divided into different user groups. Different kind of energy efficiency activities will have an effect on different user groups. The most interesting group is the household customers on the DSO’s point of view. This group is the largest in both, customer number and the supplied energy when considering the whole country. (Honkapuro et al. 2010) Changes in the household customers’ consumption habits affect significantly to the sales of the DSO. As mentioned earlier, it is evaluated that the electricity use in new buildings built in 2010-2020 will decrease approximately 23 %. It is also evaluated that electricity consumption of new electric devices will decrease in the future. Adato (Adato Energia 2008) has estimated that the total electricity consumption of household customers will stop increasing by the year 2020 because of the renewed devices. The saving potential for the year 2020 is 2540 GWh.

Other factors, besides energy efficiency, that will have an effect on the overall energy consumption in the future are population development, climate change and economic situation. Statistics Finland (Statistics Finland 2009) has evaluated that the population growth will continue quite fast until the year 2030. This will increase the electricity consumption. Climate change will raise the average temperature in Finland by 2,3 degrees Celsius by the year 2030 from the 1971-2000 level. This will reduce the need for heating, but on the other hand the need for cooling will increase. Recession has reduced the electricity consumption of the industry in the past few years. However, a long-lasting recession can increase the electricity consumption among the household customers. This is because people spend more time at home as a result of unemployment and reduced number of trips abroad. Electricity can be seen as a necessity of which customers are not ready to give up easily. (Elinkeinoelämän keskusliitto EK ja Energiateollisuus ry 2009)

Targets to improve the energy efficiency and the possible decrease in the volume of the traditional electricity distribution business create incentives to develop new business opportunities and services. The technological development, especially the interactive customer interface could help the introduction of new services that will help to improve the energy efficiency. AMR have a key role in many of them, like both in demand response and in fixing the consumption forecast. With more precise consumption forecast the electricity producers and retailers are able to plan their production and purchases from the Spot- and Elbas-markets so that the need for expensive balance management electricity will minimize. On a large-scale the demand response could provide significant financial savings and improvements in the energy efficiency. During special occasions such as peak power hours, demand response can bring great benefits. Demand response could also reduce the investment need to the grid and bring savings for the DSOs. (Honkapuro et al. 2010)

In addition, one service opportunity is different kinds of electronic devices such as displays, load guards and HEMS solutions, which able the customers to monitor the electricity consumption and help to improve the energy efficiency. Energy saving impact of these devices has been evaluated in numerous studies. The saving potential is greatly dependent on customer’s activity but on average the saving potential is estimated to be from 5 to 15 %. The role of different market actors providing these services is not straightforward yet. Possible service providers are energy retailers, DSOs or third party actors. The challenge is to get the cost of new technology to the economically lucrative level.

4 NETWORK TARIFFS

In the future, there will be some significant changes in the electricity market that will affect to the future tariff structure. Energy efficiency, energy saving actions, energy storages and distributed generation will reduce the amount of transferred energy. However, these changes do not reduce the peak power considerably. Consequently, the revenue of the DSOs will decrease if the tariff structure does not change because in the current tariff structure energy-based fee still forms the majority of the DSO's revenue. These changes in the operational environment drive the development of tariff structure. In this chapter principles of electricity pricing and the formation of current tariff structure are introduced. Also requirements for the new tariff structure are provided and potential network tariffs introduced.

4.1 Principles and requirements for network tariffs

Laws and regulations that affect the selection of the tariff scheme include EU directives, the Finnish Electricity Market Act (386/1995), Act on energy efficiency services of enterprises operating in the energy market (1211/2009) and Government Decree on determination of electricity supply and metering (66/2009). The new Energy Efficiency Directive introduced earlier provides more detailed regulations on network tariffs. These laws and directives are not introduced in detail, only basic principles and obligations are provided. However, it can be stated that there are no obvious inconsistencies in the present legislation that would prevent the implementation of the tariff structures discussed later. (Partanen et al. 2012)

There are different principles and obligations in the network business and network tariff design. According to the Electricity Market Act the pricing of the electricity distribution must be based on spot pricing which means that the DSOs must make sure that a customer is able to use the whole electricity network, excluding external links, at his junction point. It also states that the pricing of the electricity cannot vary according to customer's geographical location in the DSOs area of responsibility and that pricing must be cost-correlative so that each customer group would only pay the costs they have caused as far as it is possible to specify. In Finland the pricing system is planned in a way that it fulfills the requirements for spot pricing demanded by the Act. (Partanen et al. 2011) The pricing is also based on the matching principle and at the same time the system must be simple enough and easy to understand. It is very important to obey the non-discrimination and equity principle in cost allocation. In addition, transparency is needed in the whole tariff structure in order to provide predictability. These principles are somewhat in contradictory and impossible to obey entirely at the same time. That is why compromises have to be done.

In addition to these pricing principles, it is very important that network tariffs support European Union's climate and energy policy as well as energy efficiency targets. This means enabling demand response and small-scale distributed electricity generation. Tariffs should give both customers and distribution companies the economic signals that make them behave in a way that maximizes the social welfare in both short and long term. Customers expect that distribution tariffs match with electricity retail tariffs. Customers should also have a real opportunity to do actions that affect to the amount of their distribution fee, and predictability should ensure that these actions are worthwhile in a long-term. (Partanen et al. 2012)

From DSO's perspective distribution tariffs should provide predictable and secure income formation. Tariff structure should be cost-correlative in a way that changes in electricity consumption will have a similar effect on both income and costs. A good tariff structure encourages customers to optimize the use of electricity in a way that it benefits also the DSO. It must be noticed that both energy and power have an effect on to the energy efficiency of the electricity distribution system. In addition, tariffs should be put into practice technically in a way that the price of metering and steering is reasonable. (Partanen et al. 2012)

4.2 The formation of tariff structure

It is not possible for the customers to put distribution price out to tender, whereas it is possible to tender the retail price. The cost components of electricity price are network costs, wholesale costs, retail costs, electricity tax and value added tax (VAT). The wholesale price of electrical energy forms in Nord Pool Spot electrical energy market. The formation of household customer's electricity price is introduced in this chapter as well as current network tariffs. After that the reader is provided with a description of cost allocation.

4.2.1 The formation of household customer's electricity price

A quarter of household customer's electricity price comes from distribution network. Other costs come mainly from electricity production and taxes. The taxation of electrical energy consists of VAT and electricity tax. VAT is also charged of electricity tax. There are two different electricity tax classes in Finland. Domestic customers, public sector, agricultural entrepreneurs and service sector customers belong to tax class 1. Companies that are industrial manufacturers and professional greenhouse cultivation customers are eligible to lower tax class 2. The electricity tax is energy-based; therefore the more customers consume electricity, the more expenses there are. The difference between the formation of electricity price of household customers and household customers with electricity heating can be seen by comparing figure 4.1 and 4.2. Household customers with electricity heating are consuming 19 MWh on average per year and customers without electricity heating 7 MWh. (Adato

2008) Average electricity prices were 12.28 and 14.98 c/kWh on July 2012, respectively. (Energy Market Authority 2012d)

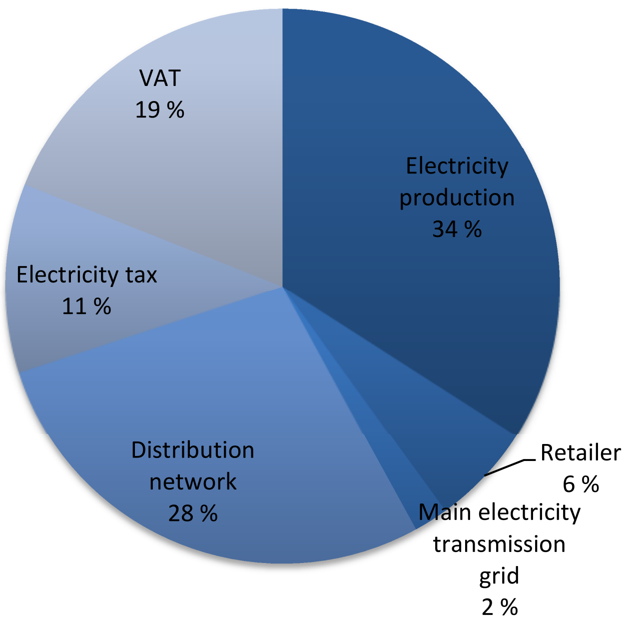

Figure 4.1. *The formation of household customers' electricity price. Modified from (Energy Market Authority 2012d)*

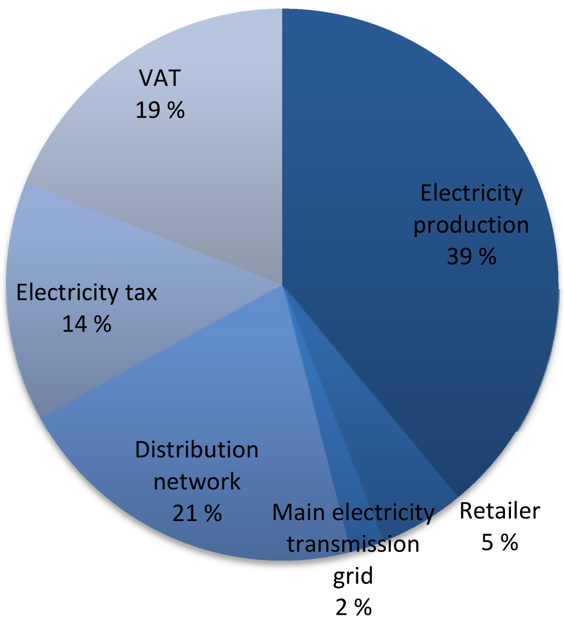

Figure 4.2. *The formation of the electricity price of household consumers with electric heating. Modified from (Energy Market Authority 2012d)*

Electricity distribution tariffs consist normally of fixed charge and energy-based distribution fee. In power-based tariff there is a fee based on power demand and it is meant for customers using greater amount of electricity.

Basic fee is a fixed monthly payment (€/month). The basic fee is usually based on the main fuse size of the connection point. The main fuse size is the only limitation for the customer's maximum power. The most common main fuse size is 3x25A. The bigger the main fuse, the bigger the basic fee is. In this way it encourages customers to choose smaller fuse size. The aim is to rate the network for smaller capacity which possibly results to reduced investment costs. However, peak power is not comparative to total yearly energy consumption and consumers may have difficulties in estimating the main fuse size because of that. The AMR will help to choose the right fuse size so that it would not be overrated. Basic fee provides predictable and secure income formation for DSO, because the volume of transmitted energy is significantly influenced by the outdoor temperature. The downside of the basic fee is that it does not motivate to save energy.

Distribution fee is an energy-based fee (c/kWh). It encourages customers to use electricity more effectively but it also can cause a risk to the DSO if electricity consumption decreases. Household customers accept the energy-based fee easier than the fixed charge fee. The distribution fee can be considered as a transfer of income from large customers to small within a similar tariff class, because otherwise the basic fee would be very high for small customers. (Partanen et al. 2011)

Power fee is based on power demand (€/kW, time period). Active power usage has so far mostly been measured only from customers with power distribution tariff. AMR will bring change to that by enabling power measurements from all customers. Peak power demand is the most significant component when designing the distribution networks; therefore the use of power fee is justifiable. In addition to active power fee, there is also a reactive power fee for some customers. Almost all customers consume reactive power but usually it is non-chargeable up to a certain level. The reactive power fee encourages customers to compensate their reactive power in the cases it is economical.

4.2.2 Current network tariffs

General distribution tariff

General distribution tariff consists of a basic fee, which is usually based on the main fuse size, and an energy-based distribution fee. General distribution tariff is suitable for small customers who consume electricity less than 10 000 kWh in a year and mostly in daytime. The ratio of basic and distribution fee varies among DSOs. The basic fee has increased clearly in recent decade and at the same time the energy-based distribution fee has decreased. (Energy Market Authority 2010)

Night-time distribution tariff

In night-time distribution tariff there are a basic fee and an energy-based distribution fee that is lower during the night-time. The night-time distribution tariff is suitable for medium-size customers with electric heating or electricity storage heating and also for farmers. Yearly electricity consumption is usually more than 10 000 kWh. Lower tariff is in place from 10pm to 7am. The purpose of having lower tariff during the night-time is to prod customers use electricity when the overall consumption is lower so that the network would be used as efficiently as possible. A more even load profile will reduce network losses and investment costs. Problem related to this tariff is a significant power peak at 10pm, if all the loads are switched on at the same time. To avoid that, DSOs switch on the loads in stages. (Energy Market Authority 2010)

Season distribution tariff

Season distribution tariff suits a customer who can supplement electric heating with other alternatives during winter time. The energy-based distribution fee is lower all summer and during nights and Sundays in the winter time. Winter season is from November to March. This tariff aims to prod customers to reduce the use of electricity during winter days when the network is most loaded and the most expensive forms of electricity are used.

Power distribution tariff

Power distribution is meant for large-scale customers. The tariff consists of basic fee, power fee, reactive power fee and energy-based distribution fee. The metering and charging of reactive power is compulsory for power distribution customers. There are both low-voltage power (0,4 kV) and medium-voltage power distribution (20 kV). It is also possible to choose tariff in which the distribution fee is lower during the summer time. In Elenia Verkko Oy the debiting demand of active power is defined as the average of the two highest monthly demands in the last 12 months.

4.2.3 Cost allocation

The main cost pools in the electricity distribution are metering and billing, investment costs, capital costs, operation and maintenance costs, financing costs, administration costs, purchase of loss electricity, transmission grid fee and network components and devices. Network components and devices are designed according to the peak power so costs related to them are power-based. Metering and billing costs depend on the number of customers in the operating area. Operation and maintenance costs are related to the extent and operational environment of the DSO's area of responsibility. A typical cost structure of the DSO can be seen from the figure 4.3.

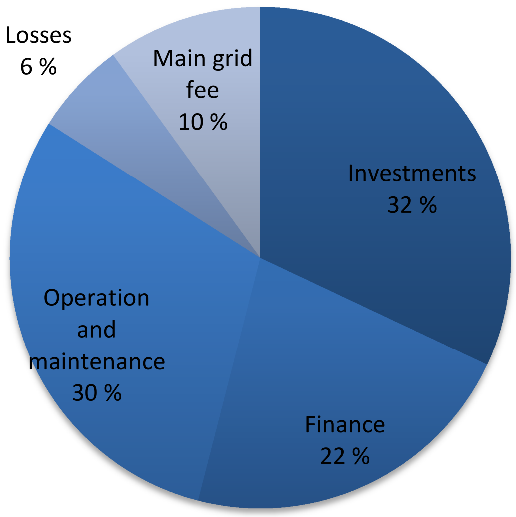

Figure 4.3. *A typical cost structure of the DSO. Modified from (Partanen et al. 2012)*

Unit costs of different cost pools must calculate and after that allocate to different parts of the tariff. There is no legislation on how the DSO's should allocate the costs to different parts of the tariff. Every DSO can do this as they want as long as they are able to justify the chosen structure. A key question is which costs are assigned to the basic fee and which are collected through the energy-based distribution fee. The costs that are not related to the amount of energy supply should be included into basic fee and the energy depended parts into distribution fee. But because only main grid fees and electricity losses are not fixed costs, the allocation of the costs is not that straightforward. Moreover, 25-40 % of the losses are usually no-load losses that are not related to the amount of transferred energy. In some situations, the no-load losses may be as high as half of the total losses if load factors of the transformers are low. (Kuisma 2008) The basic ideology of the allocation of different cost components is introduced in the figure 4.4 below. (Partanen et al. 2011)

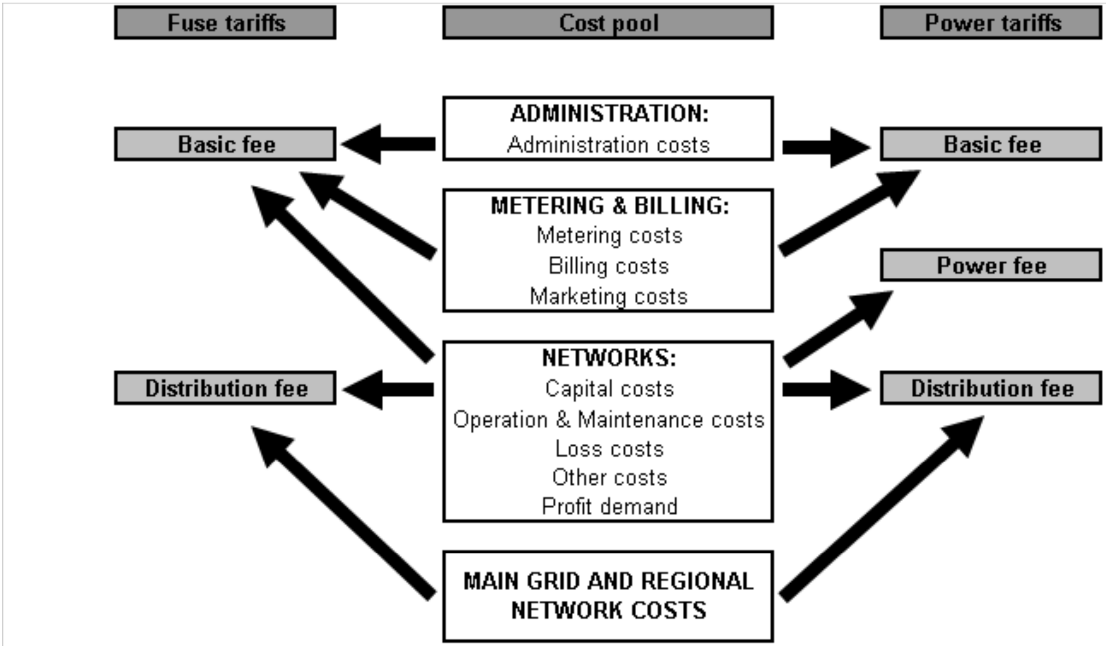

Figure 4.4. *Cost pools of electricity distribution and the cost allocation to the different tariff components. (Partanen et al. 2011)*

As mentioned earlier, a majority of the costs of a DSO are either fixed costs or depend on power, while only a minority depends on the volume of energy transmitted. Although the proportion of the fixed tariff component has increased, the energy-based fee still forms the majority of the DSO's revenue. On average 37 % of the distribution fee is collected through the basic fee in a case of single-family house customers. Among the block of flats customers the ratio is 58,2 % (Energy Market Authority 2010) Hence, the present tariffs do not correspond very well with the cost structure of the DSOs. Moreover, in the present tariff structure, the charges are not necessarily allocated to the customers by the matching principle. (Partanen et al. 2012)

Aho (2012) has investigated the pricing structure of one DSO in his thesis. The cost correlation based prices were determined and compared to the current prices. The result was that if following the cost correlation principle, 79 % of the distribution fee should be collected through the basic fee in general distribution tariff and 83 % in night-time and season distribution tariff. In the current tariff structure only 31 % and 29 % were collected through the basic fee in general distribution tariff and in night-time/season tariff, respectively. Even though the cost correlation is not the only pricing principle, the result shows that there is a need for changes in the current tariff structure.

4.3 Potential network tariffs

There will be some significant changes in the electricity market in the future that will affect to the future tariff structure. Energy efficiency, energy saving actions, energy storages and distributed generation will reduce the amount of transferred energy. These changes in the operational environment drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level.

The future network tariff structure should enable the demand response (DR) in a way that also the DSO would benefit from it. Demand response means shifting the power demand away from the peak power hours and therefore, usually from peak price hours too. The most essential goal of using demand response is to level the daily and seasonal fluctuation of the power demand. One challenging question is that how to include demand response more effectively into the electricity market. DR is already working in the wholesale market and among big consumers. Now the smaller consumers should also be included into the DR actions. (Belonogova et al. 2010)

DSOs play a crucial part in affecting the DR of small customers, because they provide the necessary technical infrastructure to that end, for example, automatic meter reading systems. In practice, demand that is optimized based on generation only may be non-optimal from the distribution system’s point of view, in which case the DR products in electricity retail may produce conflicts of interest between the retailer and the DSO. This conflict situation is illustrated on the following figure 4.5. The market price-based DR could shift the consumption from the peak price hours to the hours when the consumption in a certain feeder is already at the highest level. However, with a suitable distribution tariff structure, incentives can be provided for the consumers to optimize their electricity consumption so that besides the customer and the retailer, also the DSO benefits from the DR. (Partanen et al. 2012)

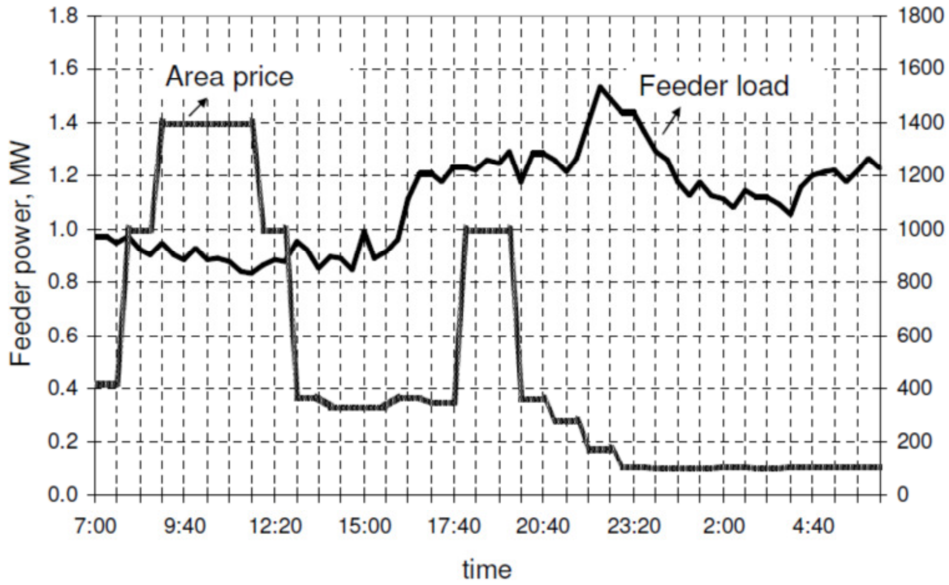

Figure 4.5. *The feeder load and the area price of Finland in cold winter day. (Belonogova et al. 2010)*

Pricing mechanisms that encourage customers to DR can be divided in two different groups. In price-based DR the price of the electricity forms in a way that the customer can reduce his electricity bill by changing consumption profile. If the price differentials between hours or time periods are significant, can customer voluntarily avoid using electricity during the most expensive peak power hours and reduce his electricity costs. Real-time pricing, Time-of-Use (ToU) and Critical Peak Pricing (CPP) are examples of price-based DR pricing. Night-time tariff is one form of the Time-of-Use pricing and is commonly used in Finland. Tariffs introduced next are based on price-based DR. In contract-based DR DSOs and suppliers have contract with the customer to perform the DR actions. The load reductions are requested either when the grid operator thinks reliability conditions are compromised or when prices are high. A compensation for customer is paid. (Honkapuro 2010)

The development of metering devices and load control possibilities will support and bring new possibilities to the new tariff structure. In Finland there have been a large reform going on when the DSOs are replacing old electricity meters with new smart meters. Electricity Market Act (66/2009) demands 80 % smart meter roll out by the year 2014. Smart meters are generally electrical metering devices that record the electric energy consumption in intervals of an hour or less. Smart meters communicate this information back to the DSO for monitoring and billing purposes on a daily basis. The data should be able to be transferred in two-way between the meter and the central system. Smart meters and AMR will enable the DR, but because of the current distribution tariffs, the household customers have a limited possibility to take part of the DR.

In principle, there are many possible ways to form the tariff structure but when considering the principles and requirements mentioned earlier, there are few actual options. Four different tariff structures are introduced next. Partanen has investigated possible tariffs in his report (Partanen et al. 2012). Power-based power band tariff is considered to be one of the best options and therefore introduced in more detailed.

First option is a dynamic energy-based tariff. This means that the price varies according to time of the day and it would be more dynamic than the present two-time tariffs. This would give an incentive for customers to use electricity more according to the DSO's needs. Distribution prices would be highest when the peak power on the distribution network is usually reached. Time steps could be constant on each day, divided into weekday, Saturday and Sunday or they could change every day and customers would be informed beforehand. The tariff is illustrated in the following figure 4.6. Problem related to this dynamic tariff is that the time when the peak power is reach is different in every customer group, therefore different types of time steps would be needed. This would lead to too complex tariff structure for the customers. In addition, the dynamic tariff might create contradictory incentives between distribution and retail tariff. (Partanen et al. 2012)

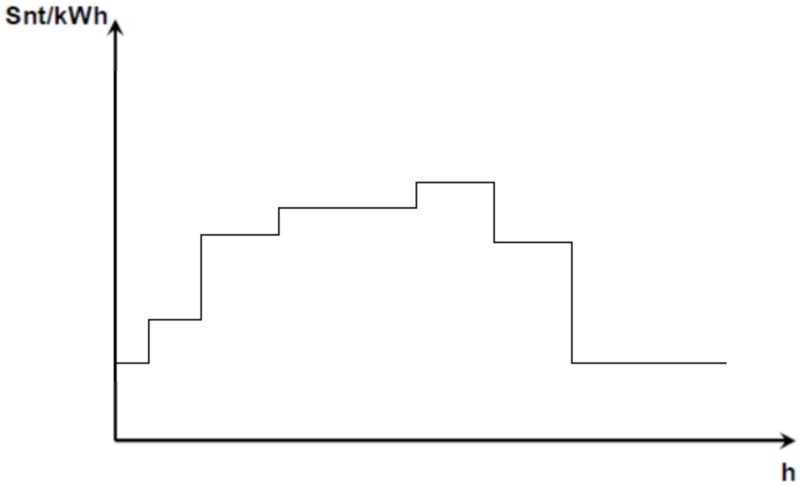

Figure 4.6. *Simplified example of the dynamic tariff. (Partanen et al. 2012)*

Perälä (Perälä 2011) has also investigated network tariffs in her thesis and the aim was to develop new network tariffs that could enable the implementation of DR in electrically heated detached houses. It was found out that from all the potential new tariffs introduced in the thesis the three-time energy & power tariff lowers the peak power and losses the most. In three-time energy & power tariff there are three different price periods in a day. Off-peak (night) price is 0,01 €/kWh, mid-peak (day) 0,015 €/kWh and on peak (evening) 0,03 €/kWh. There is also a power charge: at nighttime 8 €/kW, 15 €/kW at daytime and 20 €/kW in the evening. Basic charge would be 100 € and same for all customers. The loads are encouraged to be used during the time when there will be highest savings from reduced power losses. The drawback is that the tariff is not interactive, because the inspection period is one year.

Critical Peak Power (CPP) pricing uses real-time prices at times of extreme system peak. Critical Peak Power prices are restricted to a small number of hours per year and it is much higher than a normal peak price. These critical peak hours are often limited to 10-15 per year. The days in which critical peaks occur are not determined in the tariff, but dispatched on relatively short notice as needed. Prices can be from 3 to 10 times as much during the critical peaks. CPP is illustrated on the next figure 4.7. (Federal Energy Regulatory Commission 2008)

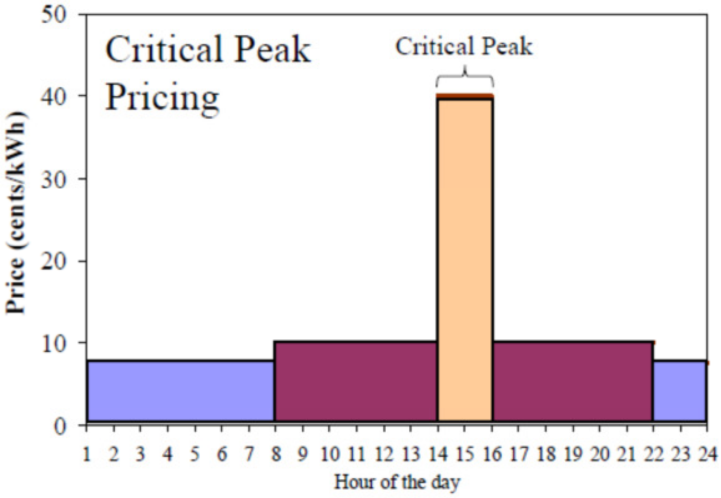

Figure 4.7. *Critical Peak Power pricing. (Federal Energy Regulatory Commission 2008)*

Next option is a peak power-based tariff, in which the energy-based distribution fee is based on the customer's highest hourly average power. AMR is required in this tariff. Today only large-scale customers use power tariff in Finland. In Sweden one DSO, Sollentuna Energi, has introduced power tariff to all customers. Case study of Sollentuna Energi is discussed in more detailed in chapter 4.4. Peak power demand is the most significant component when designing the distribution networks; therefore the use of power tariff is very justifiable. It provides a predictable income formation for DSO and is cost-correlative. This tariff would prod customers to reduce the peak power and so improve the energy efficiency. Energy fee of the retail tariff and electricity tax provide still an incentive to lower the total energy consumption. Price would be based on active power (kW). When using the power-based tariff, customer should be able to monitor or limit his power demand either manually or automatically or at least use the online-service provided by the DSO. (Partanen et al. 2012) HEMS solution compatible with power-based tariff is introduced later.

Power-based tariff can comprise different pricing models. In elastic power-based tariff the price is based on the highest hourly average power which is taken from customer's AMR data. The highest value of the year, or other time period, would determine the distribution fee. Drawback of this pricing model is that the peak power level and also the distribution fee can vary considerably which is not desirable either on customer's or DSO's point of view. (Partanen et al. 2012) Power band tariff is introduced next.

Power Band Tariff

The idea of a power band is introduced in research report called Tariff scheme options for distribution system operators, and it is was conducted by a research group of LUT Energy, the members of which were Jarmo Partanen, Samuli Honkapuro, Jussi Tuunanen and Hanna Niemelä. The most important features of the power band discussed in the report are introduced next. The evaluation of the power band concept is provided in chapter 6 after a pilot study was conducted. The evaluation is based mainly on the pilot study which is discussed in chapter 5.

The concept of a band is familiar through internet broadband. In electricity distribution this means that customer would order a distribution band he needs from the DSO. This band would determine his capacity of power demand. Today the main fuse size is the only limitation to the customer's maximum power and this does not prod customers to reduce the peak power demand enough. It is also hoped that the power band tariff would improve the understandability of the electricity distribution pricing. (Partanen et al. 2012)

The pricing of the power band tariff should be in compliance with the laws and directives related to the electricity distribution pricing. In Finland the distribution of electricity varies between different areas, such as rural and urban areas, and also the pricing schemes and prices vary considerably between the operators. However, the new tariff structure should be suitable for all DSOs and customer types. In the power band scheme, suitable steps should be found for each band so that the monthly charge still increases as the band increases. Only in this way customers have incentive to choose the smallest possible band. However, the price steps cannot rise along with power because in that case customer with large band would have to pay too much. Consequently, Partanen (Partanen et al. 2012) suggests that the price would be constant for each band, €/kW, in which case the pricing is fair and incentive. The price of power band would be determined based on the network operation costs, that is, the regulated revenues and volumes of subscribed power. Average distribution fees would not change and also the proportion of the distribution from the electricity price would remain the same. However, in a long term the large-scale DR could possibly lower the electricity price. (Elovaara & Haarla 2011)

Price would base either on kilowatts (kW) or amperes (A). The power demand is usually given in watts in electric devices, and it is thus easier to understand as a unit of measurement for the customers. Hence, if customer has an electronic device with power of 2 kW and he buys a new one with 1 kW, it is easy to understand the effect on the distribution fee. On the other hand, current is better unit electrotechnically because it includes the reactive power and it would remove the need to charge for reactive power. Amperes are familiar to customers because of the main fuse size applied in the present distribution pricing. If amperes were applied, the DSOs would have to modify their AMR data, which is given in kilowatts. (Partanen et al. 2012)

Currently the smallest main fuse sizes are 1x25 A, 3x25 A and 3x35 A. In power band tariff the steps should be more frequent. In the beginning the steps of 3 or 5 kW would be enough, because band crossing are more likely. It is not possible to say how customer's electricity consumption will change, but when the customers are more familiar with the band and have appropriate equipment for monitoring the power, more frequent steps are needed. There are two scaling options in the table 4.8. On the left hand side there are steps of 5 kW and on the right hand side steps of 3 kW. Even smaller steps can be considered in the future when customers are more familiar with the band. 2 kW band is probably too small band size even for the smallest customers, but a threshold for band fee is needed to set the fixed costs. The size of the customer's main fuse would remain the same in spite of the power band size. (Partanen et al. 2012)

Table 4.1. *Two scaling options for power band tariff. On the left hand side there are steps of 5 kW and on the right hand side 3 kW. Modified from (Partanen et al. 2012).*

Main fuse (A)	Power (kW)	Band (kW)	Main fuse (A)	Power (kW)	Band (kW)
		5			2
		10			5
25	17	15			8
		20			11
35	25	25			14
		30	25	17	17
50	35	35			20
		40			23
63	44	45	35	25	25
					29
					32
			50	35	35
					38
					41
			63	44	43

Opinions vary on how the power band size of an individual customer should be determined. Based on the flexibility of the power band, it may be considered that the customer's power band could be determined for instance based on the 10th highest hourly power. If some flexibility is included in the determination of the highest hourly power, the customer pricing could also be based on the mean value of the 10 highest hours. However, calculations show that there is not a major difference in these two methods from a customer's point of view. For DSO it is more troublesome to calculate the average values, so the average method can be left out. Instead, bigger differences arise if the value used is the 30th highest or the highest hourly average power of the year. Customer's highest peak powers are usually few kilowatts higher than the rest of the average consumption. It can be assumed that the introduction of the power-based tariff would lower the peak powers because customers would start to pay attention to their power demand and have equipment for monitoring it. Calculations show that when using the power values lower than 30th highest, there is no significant difference in them anymore. Hence, Partanen (Partanen et al. 2012) suggests that the size of the band would be determined by the customer's highest hourly average power of the year and exceeding the band would be allowed. The distribution fee would be the same every month throughout the year.

If the size of the band is based on the highest power of the year, excess usage events are not very likely. However, it is important to give customers the opportunity to choose smaller bands and then excess usage events became more likely. From the customers' perspective and for the sake of flexibility of the power band pricing, it would be justified to allow the customer to exceed the band. One option is to determine certain amount of allowed excess usage events for different band sizes. For example, a customer with 5 kW band would be allowed to exceed the 5 kW limit 10 times and customer with 20 kW band 50 times. Allowed excess usage events can be seen from the table 4.9. Events of excess usage of the power band are not very harmful to the network, as there is usually some flexibility involved in the present networks. Moreover, there are 8760 hours in a year, and hence, the10th highest hourly power accounts only for 0.1 % of all the hours of the year. Excess usage events would be observed by the DSO so customers would not have to look after that. If the number of allowed excess usage events would be exceeded, the DSO would transfer the customer to a bigger band automatically. (Partanen et al. 2012)

Table 4.2. *Allowed excess usage events. On the left hand side there are steps of 5 kW and on the right hand side 3 kW used. Modified from (Partanen et al. 2012).*

Power band (kW)	Number of events of excess power band usage	Power band (kW)	Number of events of excess power band usage
5	10	3	5
10	20	8	15
15	30	11	25
20	50	14	30
25	75	17	35
30	100	20	50
		23	70

Other option is a fee for excess usage events. There are customers whose power demand varies within a year, such as agricultural manufacturers, small industries and entrepreneurs. For example, agricultural manufacturers may have significantly higher power demand during the harvesting season. Band is exceeded so many times that the allowed excess usage events would not make a difference. If the price would be determined by the highest power, the distribution fee would become very high and not suitable. Therefore, it would be good to have an opportunity to exceed the band during one or maximum two months and pay an extra fee. If there are excess usage events during three months or more, the DSO would have a right to transfer the customer to bigger band group. It is not reasonable to allow excess usages for more months than two, because the model becomes too complicated to apply. The excess usage event fee should be bigger than the regular band price of the one size larger band, so that customers would still try to avoid exceeding the band. (Partanen et al. 2012)

Oversized bands are unwanted. It means that the customer has ordered too large band when smaller band would be enough. By monitoring the hourly power used as the basis for billing, the information system could detect that the customer can do well with smaller band size and transfer the customer to smaller band automatically. This practice could be applied also in determining the band size. DSOs would determine the size of a customer's band, but customers would have a right to change it. There should be a fee when transferring to smaller band so that customers could not speculate with the size and price of the band. (Partanen et al. 2012)

Transition to the power band tariff

Transition from the current tariff structure to the power band tariff should be done in stages. First only the basic charge of the current tariff would be replaced by the power-based band fee. In case that the power band is wanted to be used on a large-scale in all DSOs, the regulator must set a decree of that. Every DSO should have similar band tariff, including the band scaling, so that it would not cause any confusion to customers and all customers would be in equal position. Also the introduction year should be the same for every DSO. The power band could be introduced at the earliest when all DSOs have started to use AMR and have had time to get the meter reading act properly. The portion of the band-based charge could be gradually increased during several years. It is important that the changes are not too radical. (Partanen et al. 2012)

A lot of informing is needed to get the transition run smoothly. Customers should be informed widely by the DSOs and also in the media. DSOs should provide information about the new tariff on their websites and in the bills. In the bill there would be the highest average power of the previous year provided and an estimation of the band size based on that. There should also be information on how to reduce the band size and what kind of equipment for monitoring and limiting the power demand there are available. OnLine-service provided by the DSOs will support the transition by helping customers to explore their consumption data and also power consumption level. Although the average distribution fees will not change, it must be remembered that when changes happen always someone's fee will increase whereas others decrease. (Partanen et al. 2012)

One of the main reasons contributing to the rise of power band tariff is its positive energy efficiency impacts both from the customer's and DSO's perspective. Nowadays the ideal way of operating the power system is to keep the power fluctuation as small as possible. When a customer decreases his power consumption and chooses a smaller band size, it can be seen as a demand response. Demand response means that a customer is not using all his electronic devices at the same time but in a way that the load profile is as even as possible by shifting or removing his consumption. If he manages to do it, both demand response and energy efficiency from customer's point of view will come true. (Partanen et al. 2012)

Decreasing the peak power will also help to improve the overall energy efficiency of the power system. During the power peaks most of the electricity is generated by using the most polluting energy sources, such as gas turbines and oil. If the power peaks can be decreased nationwide, the most polluting electricity generation is not needed and in that way the energy efficiency improves. Distributed energy production utilizing renewable energy sources becomes constantly more important. One major problem related to that is the great fluctuation on daily and seasonal production. Because it is difficult to forecast the energy yield, demand response is needed to compensate the difference between generation and demand. In the future, smart grids enable flexible connection of distributed generation, energy storages and controllable loads to the grid and their smart control. In addition, losses of electricity transmission and distribution are proportional to the power; hence reducing the power demand will decrease the losses. (Partanen et al. 2012)

The goal of the power band is to decrease the peak power level. That would relieve the stress on the distribution network while also temporarily postpone the need for network renovation. It must be emphasized that these benefits only occur if the power level is reduced and will remain at the reduced level. This would need real actions from customers. In order to achieve desired results, proper equipment for limiting the power, such as HEMS, is necessary. HEMS needs investments and not all customers are willing to do them. In addition, saving level is highly related to the activity level of the consumer, so only investing in the HEMS will not guarantee savings automatically. It is difficult to predict the activity level of the customers and what factors affect to the customers' behavior and in what way. That is why the estimation of the power level that could be achieved and demand response potential is very difficult. One worrisome question is whether the power band can prod customers to increase their energy consumption, because the electricity distribution is charged only by the power level not energy consumption. In addition, understandability of the power band will be one major issue contributing to the final result.

Pyrko (Pyrko J. 2006) has stated some important issues when introducing power-based tariff. According to him, electricity pricing should reflect real marginal costs of electricity production and the utilities' costs. In many situations customers really want to "help" the society, and even their DSO, to avoid problems and shortages. Therefore, promotion of a new tariff requires a solid and carefully prepared information campaign. It is very important that the purpose of such a tariff is clearly introduced to the customers from the very beginning. The difference between "power demand" and "energy use" is not easy to understand for the majority of customers. They need help to gain a better insight into how their electricity costs will depend on their habits and usage of appliances and installations at home. In addition, he suggests that a conceivable solution for a DSO could also be to offer its customers installation of diverse electronic devices (displays, load guards, soft heating systems) helping them to monitor the power demand. Together with the new tariff, these investments should be paid back in a relatively short time, helping at the same time to lower power demand in the grid, so it is a win-win solution for both partners.

A description of power band distribution tariff is now provided. Advantages of the power band are stable income formation for DSO and constant monthly distribution fee for customers. For the customer, the power band pricing scheme would be cost reflective, as the customer would only pay for the network capacity he/she has used or reserved. It is possible to transit to the new tariff without any large investments or new technology, excluding AMR which is already under its way. (Partanen et al. 2012) But before the power band is widely piloted on customers, it cannot be known whether the effects are desired. There might be problems with the understandability or the customers may feel that there is not enough incentive to do any actions to decrease the power. Also one constant distribution charge throughout the year may cause lack of incentive during the summer season. A pilot of power band tariff and HEMS solution supporting the tariff is introduced in next chapter and effects of the power band are discussed in more detail.

4.3 Case Study: Sollentuna Energi

Sollentuna Energi is operating in Stockholm area and has approximately 24 000 customers. From January 1st 2001 Sollentuna Energy introduced a new electricity tariff with differentiated power charges to all residential customers in its service area. It is the first energy utility in Sweden to have incorporated power charges into its network tariff. The network tariff consists of a basic fee that depends on the customer's fuse size and a power charge. The power charge depends on the customer's average power value of three daily 1-hour power peaks during one month. During the wintertime the power charge is twice as much as in the summertime. The main objective was to make end-customers more conscious of power demand problems. The long-term aim was to lower the power demand for the entire service area in order to avoid expensive investments necessary to strengthen the grid and transformations. (Pyrko 2001)

The DSO introduced the new tariff in a broad campaign explaining power demand terms and giving many advices about different ways to lower the power demand in residential buildings, with and without electrical heating. The experience from Sollentuna Energi shows the importance of customers' understanding the difference between "power/load" and "energy" terms. (Pyrko 2006) In a study made on 1020 of Sollentuna Energi's customers (Fernström P. 2002) 78 % preferred the old tariff to the new one. Some argued that it was bothersome to have one more thing to think about concerning the electricity bills. Others argued that the new tariff created higher and unfair electricity costs.

Perez (Perez Mies 2002) has investigated how the power demand component can modify patterns of electricity consumption in Swedish residential buildings and economic benefits that can be achieved. Fifteen of Sollentuna Energies customers were analyzed. These customers were from three different categories: flats, villas and semi-detach houses. An economic study was conducted, in order to establish the changes in electrical expenses for customers due to the new tariff. Also changes in consumption patterns were investigated from the utility point of view, in order to find out whether the objectives have been reached. A general overview of the fifteen customers, highlighting the most relevant relationships among them, is provided next.

The study showed that all customers saved money with the power tariff. The amount saved varied from 3 to 20%. Customers with the lowest consumption achieved the highest benefits. The main goal of the new tariff was to lower the highest peaks of the year and in order to find out whether this goal was achieved, a new factor was defined. This factor is called Sum-Factor and is calculated as follows:

$$Sum - Factor = \frac{\sum(The\ 20\ highest\ peaks\ in\ 2000)}{\sum(The\ 20\ highest\ peaks\ in\ 2001)}$$

Year 2000 is the comparison year and the traditional distribution tariff was used then. If this factor results in values higher than 1, it means that the new tariff has worked, since the sum of the highest values of the year has been reduced. The higher the Sum-Factor the greater the reward provided by the DSO should be. However, it can be seen from the figure 4.10 that there is no relationship. This means that the new power tariff does not work efficiently because it does not sufficiently reward those customers who have reduced their maximum power peaks. Moreover, all customers have achieved a reduction in their electricity bill, but just 6 out of 15 have reduced their peak power. (Perez Mies 2002)

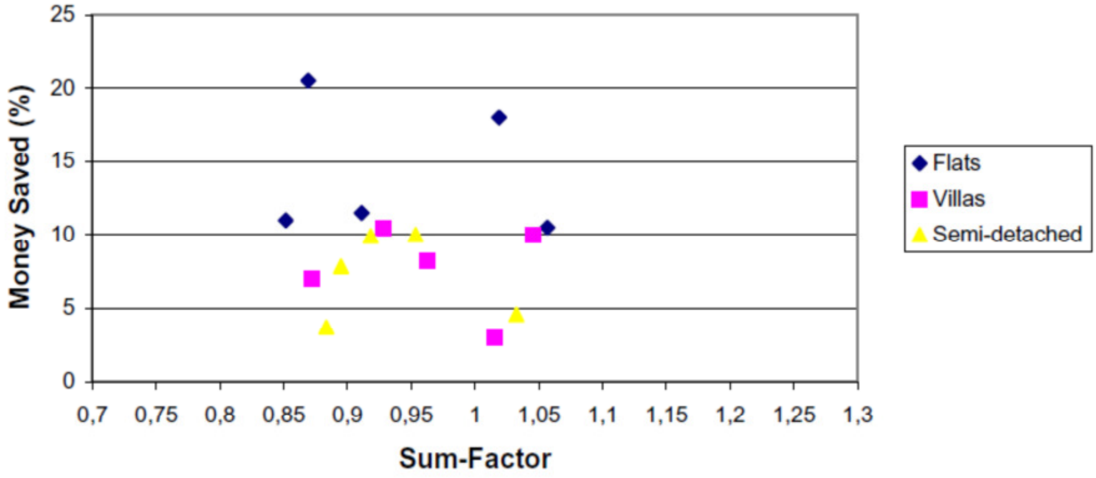

Figure 4.8. *Sum-Factor versus money saved in percent. (Perez Mies 2002)*

Perez Mies's (2002) final conclusion was that the new load tariff did not work correctly. It was not able to lower the peak load and the influence of the weather had a greater impact on consumption habits than the economic benefits provided with the new tariff. Perez concludes that "A change in customers' consumption patterns is an objective, which is not easy to achieve. Many customers do not care about their electricity tariffs and bills. Nevertheless, with increased information and appropriate incentives, it is possible to improve the patterns of electricity use." He states that the incorporation of a load component in tariffs can be a good solution to load demand problems, but this load tariff has to be correctly constructed. (Perez Mies 2002). However, a later internal evaluation undertaken by the utility suggests that the demand charge has brought about a cut in peak demand by 5 %. (Pyrko 2006)

5 CUSTOMER PILOT OF POWER BAND TARIFF

In this chapter the most important research methods and equipment used are introduced. The main target of the pilot was to examine how the Home Energy Management System supports the power band tariff and demand response. In the previous pilot, done with partially same customers, target was to learn more about the possibilities and requirements of HEMS while also evaluating the most potential functionalities of such systems. (Aalto 2012) Potential benefits from the customer's point of view were also analyzed in the previous pilot. In this pilot study, a new steering algorithm was introduced. The steering algorithm was developed to support the power band tariff. The basic idea of the algorithm is to steer to switch off loads during the power peak. The goal was to investigate whether the HEMS combined with the steering algorithm is able to allow smaller band sizes for the customers. It was also investigated how the DSO could benefit from the demand response in purchasing of network losses and what additional value HEMS could bring to the DSO.

The whole process from the customer selection is introduced in detail as well as problems appeared during the pilot and customer feedback. In addition, the steering algorithm used in the HEMS is explained in this chapter.

5.1 Background and the basic concept of the pilot

Vattenfall Verkko Oy and There Corporation started a pilot study of Home Energy Management System in June 2011. This pilot was running until the February 2012 and after that it was evaluated that the pilot could be further developed and continue with new focus. The new, current pilot started in May 2012 and was planned to run until February 2013. The steering algorithm was completed to be introduced in November 2012. Four out of five previous customers decided to continue in the new pilot. One customer could not continue because of technical reasons, hence one new customer was selected.

There Corporation offers a platform for Home Energy Management solutions to enable sustainable future proof solutions and services, such as real-time energy monitoring. The company focuses on next generation smart metering to improve the energy efficiency. (There Corporation 2012) There Corporation's role in this pilot was to develop the steering algorithm and deliver the required devices and systems. They also offered technical support.

The most important single component of the pilot was the ThereGate-unit (TG). It is a technology-independent open Linux-based platform that supports the most common smart home technologies. (There Corporation 2012) The TG collects and stores wirelessly measurement information from the metering devices. These measurements can be monitored through a web-based user interface. The monitoring can be made with any device equipped with an internet connection, meaning laptops, PCs as well as cell phones. In this pilot the customers were provided with an iPad tablet computer for this purpose. TG supports a wide number of different sensors, actuators and systems using various communication technologies like WLAN, 3G and Z-wave. Z-wave was used in this pilot. It is a wireless communications protocol designed for the home automation purposes. The concept of the TG based HEMS solution is illustrated in the following figure 5.1.

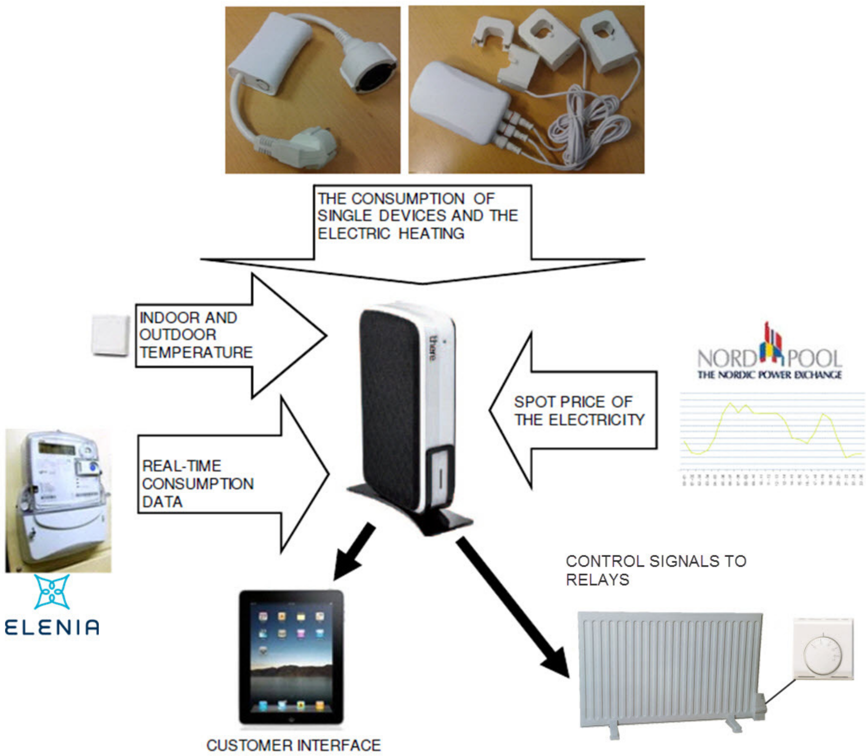

Figure 5.1. *The basic concept of the TG based HEMS solution. (Modified from Aalto 2012)*

Different types of sub-meters can be added into the system. In the first pilot it was desired to measure the power demand of the electric heating. For this reason, the sub meters were installed to the main cabinet to meter the consumption of the heating circuits. Also so called Smart Energy Switches (SES) were used. Smart Energy Switches are plug-in-meters placed to a socket and used as a sub meters to be able to meter a single device's or device group's consumption. SES also allows user to remotely switch off or on devices that are behind the meter by using the web-interface. (Aalto 2012) SES communicates by Z-wave protocol. Aeon Lab's SES device is on the figure 5.2.

Figure 5.2. *Smart Energy Switch, SES.*

Thermometers were installed to meter the inside and outside temperature. Thermometers were used to help the customer to keep the inside temperature suitable. In addition, relay switches were installed to be used in the steering of the loads. Relay switches also communicate by Z-wave protocol and they get the steering signals from the system.

A led-sensor collected the readings from the Elenia Verkko Oy's metering device. Sensor reads the blinking led-light on top of the metering device. The blinking light reflects the energy consumption. The pulse constant was 1000 pulses/kWh. (Aalto 2012)

TG-system used in the pilot was quite simple and the focus was on the energy efficiency and demand response. However, There Corporation's solutions can also be seamlessly integrated with other safety and security devices, such as motion detectors and cameras. (There Corporation 2012)

TG-system also enables the use of electricity spot-price based load control. TG receives the information of NordPool spot prices from the server and uses this information to steer loads that are under control. User can determine the amount of desired heating hours and TG directs the heating on the cheapest spot price hours. TG receives the information of NordPool spot prices from the server. Customers of the pilot were not offered an hourly based energy contract so the steering did not have any actual affects to the electricity bill of the customers.

5.1.1 User interface

Web-based user interface enables consumer to monitor energy consumption in real-time, which is a great benefit. The consumption can be monitored even with a one minute time scale and the delay is minimal. There are different time periods from last 10 minutes-view to last year-view available when monitoring the consumption. Main consumption data in one hour-view is presented in the figure 5.3. All the energy consumption data can be downloaded from the system in order to do further analysis with a help of computer software like Excel. Also controlling the devices with the web-based user interface is possible.

Figure 5.3. *Main consumption data in one hour -view.*

There were two different user interfaces between which the customers could choose. Full interface provides all the information there are available and allows the access to the system configurations. Mini version is more simple and good for example cell phone browsing. The start-up menus of the full interface and mini version are presented in the figure 5.4. Full interface is on the left hand side.

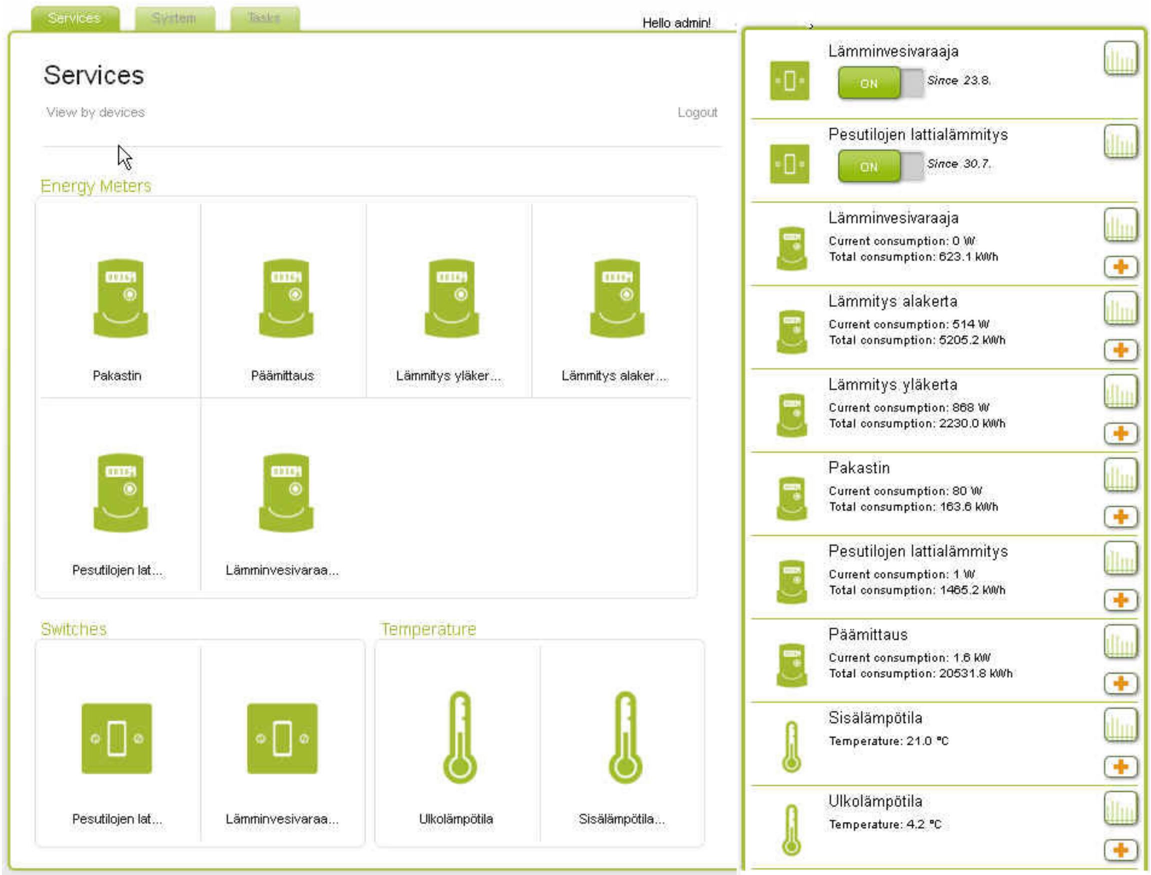

Figure 5.4. *The full interface -view and mini version.*

5.1.2 Customer selection

Five customers were selected to the first pilot in June 2011 and the main goal was to find motivated and truly interested people who would be willing to give feedback and actively use the system. Also characteristic for these households were relatively high energy consumption in the past year, so it was estimated that there could be a big potential for more efficient energy use. (Aalto 2012) All selected customers proved to actively participate in the first pilot and all of them were willing to continue in this second pilot.

There were some technical requirements for the pilot customers and especially during the second pilot some problems appeared. All customers had an own internet-connection which was needed in the pilot. TG-unit had a wired connection to the router but a wireless connection is also possible. Readings from the Elenia Verkko Oy’s metering device were transmitted wirelessly from electricity main cabinet. This sets requirements for the distances between these devices. The smaller the distance between the main cabinet and the internet router would be the better. (Aalto 2012)

Before installations could be planned the households needed to investigate in order to find out whether electrical installations were able to carry out. The distances between different devices were estimated because all the data was transferred wirelessly. Long distances and some construction materials can weaken the signals. Also the free space in the main cabinet needed to be evaluated because all meter types require different amount of free space in the main cabinet and in the DIN-rail. Even if the electrical diagram of the main cabinet is available the situation in the main cabinet must always be investigated on-site because only in that way it is possible to see how the different circuits and wires are placed. (Aalto 2012) An electrician was needed in the visits.

The target of the study changed in the second pilot and new functionalities were needed. In order to pilot the power band tariff, more loads that could be steered were wanted to add to the TG-system. New visits to customers' households were done to investigate what loads could be steered. All visits were done during the working-day which was a bit difficult occasionally as sometimes customers had a tight schedule of their own. Because the customer selection process and installations are quite time-consuming, it was hoped that all the same customers would be able to continue. However, in one case there were not any loads that could be added to the system, so it was decided that this customer will not continue in the pilot. In this household there was an air-water-heat pump heating the water used in the heating system and in hot water boiler. The heat pump had steering opportunities itself so it was not possible to use the HEMS for steering it. Electric heating is the most energy consuming part of the household and for piloting the power band tariff properly, it was wanted to include the HEMS steering.

New potential pilot customers were searched among the customers who were interested in joining the first pilot. The most important requirement was a direct electrical heating system that could be steered to switch off with the HEMS. The information, collected from eight customers who were contacted during the first pilot, was investigated. It was found out that many households with direct electric heating system had thermostats in each room or other steering automation that could not be steered with the HEMS. Quite a few thermostats have temperature drop functionality, especially the newer ones, which can be steered with the HEMS, but the more automation the thermostats contain the more difficult it is to steer with external equipment. For example, thermostats with own timer will break down eventually if steered with the HEMS. It was preferred to use the temperature drop functionality of the thermostat instead of switching on/off the entire heater. The temperature drop functionality decreases the temperature usually by 3-5 degrees Celsius and when the lower temperature is reached the heater switches on in order to maintain this temperature. So in case of system failure, the temperature will not decrease lower than the drop is. The use of temperature drop functionality set requirements for the thermostats and on how they were installed. In addition, some customers with direct electric heating had bought heat pumps to replace the electric heating. In that case the electric heating was used only as a secondary heating method to support the heat pump during cold wintertime. Because of these reasons, suitable customers could not be found among these eight customers.

Consumption data of the other customers who showed interest towards the first pilot was investigated next. Customers with electric storage heating could be found out and excluded based on the consumption data. Finally, a suitable customer was found. Customer had direct electric heating and thermostats with temperature drop functionality in most of the rooms. After a first visit it was found out that customer met all other technical requirements too. During the visit all the electric radiators had to be investigated individually to find out how they were installed. Sometimes there is a wire between the thermostat and the electricity main cabinet in which case the steering relay can be placed in the main cabinet. Otherwise it must be placed next to the thermostat and cover with an extra case if it does not fit inside the thermostat. An electrician was needed to participate to the first visit. The visit took some time because all the radiators had to be investigated individually. Especially in the older households it can be quite time-consuming to investigate how all the original installations are carried out.

5.2 Installations and functionalities

The goal was to pilot the power band tariff in which the consumption profile should be as even as possible. The consumption data of all the customers was investigated carefully. Especially power peaks were analyzed in detail and all the factors causing them were tried to found. Customers were also interviewed and solutions to lower the peak power were considered together. Power peaks were caused from many different reasons in each case. In some cases the peaks could be reduced with HEMS but also other methods were used.

Customers were familiar with the HEMS hence they had used it already for a year. They had a clear opinion on the sub-meters they felt were useless at that point and what new functionalities they see would be useful. The activity level of the customers changed among the pilot group. Almost all of the customers said they have not used the system as much as in the beginning of the first pilot. After a year, only one customer was using the system almost as often as in the beginning.

After visiting the customers the new installations needed to be planned and devices to be chosen. The situation after first pilot can be seen from the table 5.1. Customer number 3 was changed. The new functionalities of the customers are introduced next in detail case by case. The numbers of the customers equal to the numbers of the first pilot.

Table 5.1. *The functionalities of the first pilot. (Aalto 2012)*

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Real-time energy consumption measurement	x	x	x	x	x
Sub meter for heating circuits	x	x		x	x
Sub meter for water boiler	x	x			x
Sub meter for heat pump			x		
Spot-price steering for electrical heating	x	x			
Spot-price steering for water boiler	x	x			
Plug-in-meter (for example for airconditioning device or consumer electronics)	x	x	x	x	x
Thermo meter for outside temperature	x	x	x	x	x
Thermo meter for indoor temperature	x	x	x	x	x

Customer 1

Customer had night-time-tariff, and both hot water boiler and electricity storage heating were on spot-price based steering. In addition to the electric storage heating, there was a direct electric heating used in the upstairs of the building. Large power peaks were caused by the electric sauna stove of 6 kW and electricity storage heating. In the main cabinet there was already an existing coupling for switching off the upstairs' electric heating when the sauna stove was switched on. The coupling had not been used until the second pilot. It was decided that it was easier to use the already existing coupling than HEMS for the same purpose. The power of the heating system used upstairs is 3 kW, so in order to fully compensate the power increase caused by the sauna stove, customer must do some additional actions too. There were not any additional loads found that customers would have been willing to include the steering algorithm. Yearly power consumption can be seen from the figure 5.5. Power is in kilowatts and there are average hourly powers of the year 2011 in duration curve represented in the figure. This customer's duration curve of the yearly power consumption was the steepest of all pilot customers. Annual electricity consumption of this customer was 29,3 MWh.

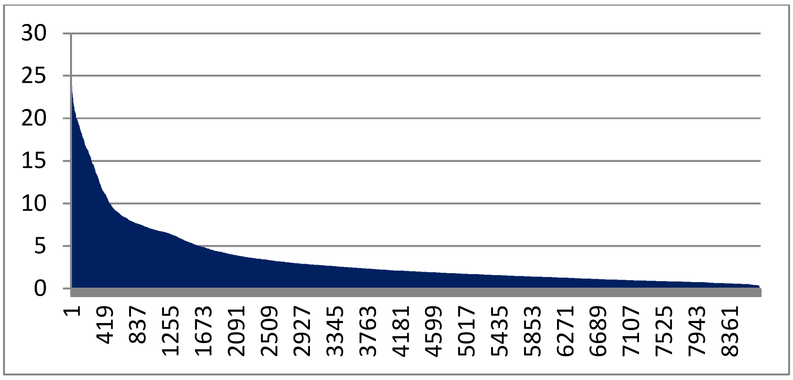

Figure 5.5. *Yearly power consumption of the customer 1 in duration curve.*

Customer 2

Any clear reasons for the occasional power peaks could not be found. Customer had night-time-tariff and both hot water boiler and electricity storage heating were on spot-price based steering. In addition to the electric storage heating, there was a direct electric heating used in the downstairs of the building. It was decided to install two relays to steer the heating in the downstairs. The heating system was divided into three areas of which two were included into the steering.

There were also direct electric heating in the garage and warehouse. It was used only in the wintertime to keep the temperature above zero degrees Celsius, so it was not included to the steering. Yearly power consumption can be seen from the figure 5.6. Annual electricity consumption of this customer was 21,5 MWh.

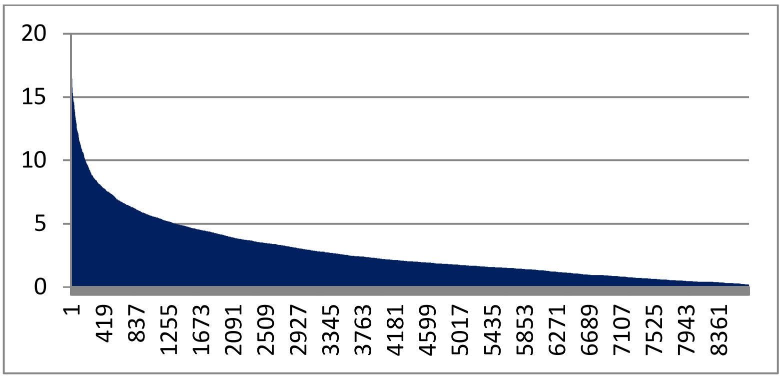

Figure 5.6. *Yearly power consumption of the customer 2 in duration curve.*

Customer 3

Customer number three was a new customer. Customer did not have electric sauna stove and any other regular power peaks could not be found. There were electric radiators with temperature drop functionality in master bedroom, kitchen, shower room and other three bedrooms, and all these were included into the steering algorithm. Three bedrooms were connected together in a way that one relay activated the temperature drop functionality in all three bedrooms. Thermometers were added to three places inside the house and one outside. Main energy consumption and hot water boiler were metered. In addition, steering relay was added to the hot water boiler so it could be steered based on spot-price. Yearly power consumption can be seen from the figure 5.7. Annual electricity consumption of this customer was 19,9 MWh. Customer number three had the most even duration curve of yearly power consumption. This customer was burning wood in the fireplace often and did not have electric sauna stove which help to keep the power level quite low.

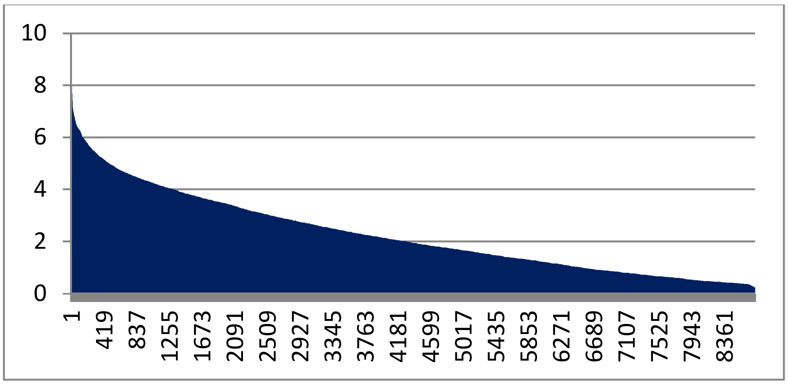

Figure 5.7. *Yearly power consumption of the customer 3 in duration curve.*

Customer 4

There were not any significant or regular power peaks seen from the consumption data. Customer was a retired person with time and urges to take some actions to achieve more efficient energy usage and savings. He was burning wood in the fireplace and wood-burning stove in the wintertime and especially when it was very cold. This decreased the peak power considerably. He was also using the HEMS actively to monitor his energy consumption.

A sub-meter and steering relay was added to the underfloor heating of the bathroom and this load was included to the steering algorithm. It was not possible to steer the heating by the customer before so it was switched on all the time. A sub-meter and relay were also added to the hot water boiler so it was possible to steer it based on the spot-price. There was no electrical sauna stove or other large loads used in this household. Yearly power consumption can be seen from the figure 5.8. Annual electricity consumption of this customer was 21,1 MWh.

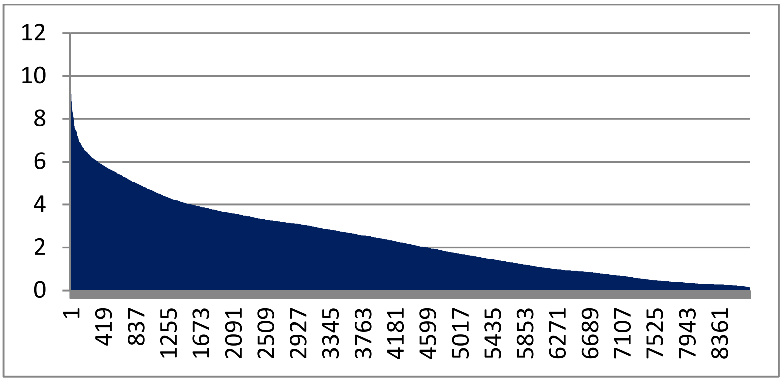

Figure 5.8. *Yearly power consumption of the customer 4 in duration curve.*

Customer 5

Power peaks occurred during night-time at around 2-5am and they were caused by the electric storage heating and hot water boiler. There was a separate steering system in the electric storage heating using thermostats with timer in each room so it was not possible to steer the heating system. Customer had a night-time-tariff and the hot water boiler was automatically switched on approximately at the same time as the storage heating. In order to minimize the time when both these devices were switched on, a DSO’s night-time delay was removed from the hot water boiler. Hence, the hot water boiler switches on 1-60 minutes earlier.

Customer had direct electric heating on the upstairs, but it was used only rarely so it would have not been useful to steer it. There was no electrical sauna stove or other large loads. Power peaks during the day-time were usually caused by consumer electronics, washing machine and stove. As the HEMS cannot lower the largest power peaks by steering the heating system, customer had more responsibility to do actions to lower the peak power. One major action customer was able to do was the use of fireplace with storage during the cold winter time. Yearly power consumption can be seen from the figure 5.9. Annual electricity consumption of this customer was 21,6 MWh.

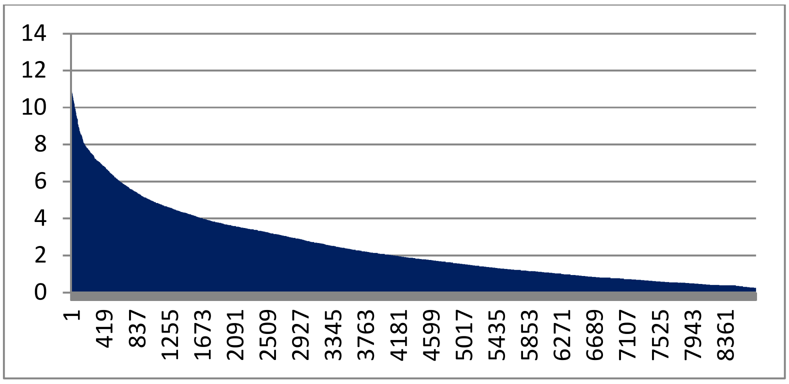

Figure 5.9. *Yearly power consumption of the customer 5 in duration curve.*

Summary of the background information of the piloted households can be seen from the table 5.2. Also number, types and sizes of the controllable loads in the steering algorithm are presented in the table.

Table 5.2. *Background information of the piloted households.*

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Annual electricity consumption (MWh)	29,3	21,5	19,9	21,1	21,6
Highest power of the year (kW)	26,1	12,9	8,9	10,9	12,5
Primary heating method	electric sto. heating	electric sto. heating	dir. electric heating	dir. electric heating	electric sto. heating
Secondary heating method	dir. electric heating	dir. electric heating	fireplace	fireplace	fireplace, heat pump
Heat pump	no	yes	no	no	yes
Electric sauna stove	6 kW	8 kW	no	no	no
Number of loads in steering algorithm	0	2	4	1	0

The installations were done by two persons. The electrician installed the sub meters and steering relays to the main cabinet while the other person focused on pairing all the wireless devices into TG-system. All the TG-units were replaced with the new ones during the installations. There Corporation instructed how the installations should be done. Installation process was quite easy to carry out even for a person with no previous experience. However, the installation process would have been a lot faster with more experienced installer. Minor problems occurred only with the pairing of the devices into the TG-system, because TG-unit needed to form a connection to each wireless meter and therefore recognize the devices from where the data should be received. This did not always work out straightaway and thus protracted the process. Installing the entire HEMS solution, including five steering relays and two metering devices, took about seven hours. The system was also tested during this time. But as mentioned just now, the installation process would probably have been a lot faster with more experienced installers.

5.2.1 Controlling of loads

Typical loads in households can be classified into four groups. *Plannable loads (PLs)* are loads for which consumption forecasts are available and it is possible to choose start times. A typical example of the plannable load is a hot water boiler. *Controllable loads (CLs)* are connected to smart plugs and can be switched on/off without damage and reduction in consumer's comfort of living momentarily. For example a direct electric heating is a controllable load. Loads that are connected to smart plugs but cannot be switched on/off are called *monitorable loads (MLs)*. Loads of which consumption can only be estimating with other measures provided by the smart meter and all the smart plugs and appliances are called *detectable loads (DLs)*. They are not smart appliances and not connected to smart plugs. Only PLs can directly participate to a load planning by enabling to choose the optimal load start time. CLs can participate to a control task by offering the possibility to be switched off when the power exceeds a certain level. Also MLs and DLs can indirectly participate to the planning of loads by giving a proper estimation of their consumption. (A. Di Giorgio et al. 2012)

It was found out that finding plannable and controllable loads that could be steered with the HEMS is not easy. Only hot water boiler and electric storage heating are plannable loads that can be scheduled to switch on for example, according to the cheapest spot-price values, without losing any comfort of living. Other heating methods, such as direct electric heating are controllable loads that can be switched off only momentarily without any reduction in comfort of living. Other loads like lighting, consumer electronics, sauna stoves and washing machine are monitorable or detectable loads that customers were not willing to include in the steering. These loads are wanted to use when it best suits for the customer, and customers feel that the comfort of living is suffering too much if these loads are switched off during power peak. Many pilot customers stated that they want to use some electric devices, like washing machines, under supervision and not for example during night-time. That is why it was difficult to include additional loads in the steering system. All the controllable loads that were included to the steering algorithm were direct electric heating loads.

5.2.2 Steering algorithm

The steering algorithm was developed to support the power band tariff. The goal was to investigate whether the HEMS combined with the steering algorithm is able to allow smaller band sizes for the customers. The algorithm removes the responsibility of steering the loads from the customers and does it automatically. The automatic steering was hoped to bring more benefit for the customers.

The steering algorithm is based on the controllable loads that can be steered to switch off when the total power consumption of the household increases. The bigger the number of the controllable loads the better. Loads that cannot be steered are not able to include into the algorithm.

So called power controller monitors the power consumption on a one minute time scale. It measures the average power of each minute. A certain power limit (kW), threshold value, is determined. When this power limit is reached, the algorithm starts to activate the controllable loads. Term load activation is used in this work and it includes both load decreasing (OFF) and increasing (ON). In the power band algorithm only OFF is used. The loads are arranged to a priority list according to the customer’s wishes. The priority list determines in which order the loads are activated. If the threshold value is reached and all the controllable loads are already activated, an SMS message or e-mail is sent to the customer to inform that the power level is high. The message is sent only when there are not any controllable loads left to be switched off, so in order to reduce the power customer must do other actions. The power band algorithm is illustrated in the following figure 5.10.

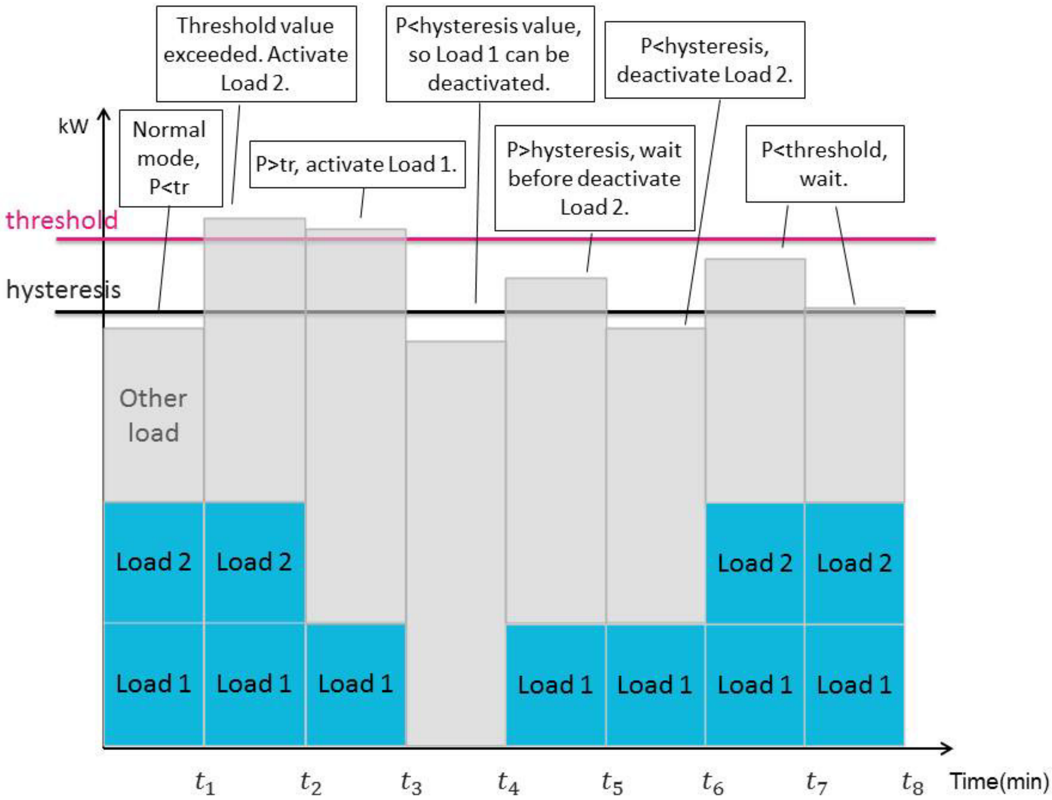

Figure 5.10. *Steering principle of the power band algorithm.*

Hysteresis value was used to prevent the unwanted rapid switching of the load. After load is switched off the system waits until the total power goes under the hysteresis value before it deactivates any loads. Without the use of hysteresis value there could be a situation in which case the load is constantly switching on and off. The hysteresis value forces the system to wait until the power level has decreased and only then deactivates the load. The hysteresis value was determined individually for each customer and it was based on the sizes of the controllable loads. The difference between hysteresis and threshold value equaled the size of the largest controllable load in the algorithm. In some cases the sizes of the loads had to be evaluated because there was no information or measurements on that.

The threshold value was also determined individually for each customer in this pilot. Because the steering algorithm was introduced only in November, the timeframe of studying it in practice was one month. For that reason, the threshold value was determined to suit for November. History consumption data from previous year was investigated in order to estimate the coming power level. Also the Heating Degree Days (HDD) was investigated. HDD is used to fix the building energy consumption so that the energy consumption of different time periods can be compared. The use of HDD in estimating the building energy consumption is based on the fact that the building energy consumption is proportional to the difference between inside and outside temperature. (Finnish Meteorological Institute 2012) However, it must be remembered that the weather can vary greatly each year and the estimation of the building energy consumption was based only on the average temperature of the reference years.

After an estimation of the power level was made, consumption data of a larger consumer mass was analyzed in order to evaluate what the suitable threshold value could be. The consumption data included hourly power consumption of 179 randomly chosen household customers having Elenia night-time distribution tariff. The data included average hourly power consumption of the year 2011. All pilot customers had also night-time distribution tariff. Power band was determined for all 179 customers according to the customer's highest hourly average power of the year. Steps of 3 kW were used and allowed excess usage events were not considered. After determining the individual power bands, one size smaller power bands (3 kW smaller) than the original were investigated. It was found out that the power was under the smaller power band limit in 99.5 % of the hours on average. This means that in order to reduce the band size for one size customers must cut the power in 0,5 % of the hours, meaning 44 hours in a year. When applying the similar analysis for two size smaller band (6 kW smaller) the corresponding percent was 92,9 %. This equals 622 hours in a year. These values are collected to the following table 5.3.

Table 5.3. *Evaluation of reduction possibilities of power bands.*

	Powers under the band limit, %	Powers that exceed the band limit in a year in hours
Band size according to maximum power	100	0
3 kW smaller band size	99,5	44
6 kW smaller band size	92,9	622

Because these percent values were determined based on power consumption of an entire year, they cannot be directly applied for shorter periods. Coldest days of the winter cause power peaks which are usually few kilowatts larger then rest of the hourly powers. Power peaks in November are usually smaller and the power level is more even. However, percent values helped to give some indication of what the threshold value should be in order to achieve smaller power band sizes. Number and size of the controllable loads were also considered in evaluating the threshold values. The bigger the number and size of controllable loads the lower the threshold value could be. Two customers did not have any controllable loads but the steering algorithm was applied for them too. It was wanted to investigate how only the SMS-alarm affected to the customer's behavior and to find out in which situations the peak powers occurred. Threshold and hysteresis values can be seen from the table 5.4. There are also highest powers of the year 2011 in one hour scale and numbers of the loads in steering algorithm in the table. Customer billing is based on hourly average powers which are considerably lower than average powers of one minute used in the algorithm. That is why they cannot be compared directly. It must be also noticed that the estimated average temperature was few degrees Celsius which is quite high temperature if you compare to the winter temperatures. Also the threshold value wanted to be quite strict in the beginning of the pilot.

Table 5.4. *Threshold and hysteresis values of the pilot customers.*

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Threshold value (kW)	14	6	4	5,5	7
Hysteresis value (kW)	1	0,8	1	1	2
Highest power of the year (kW)	26,1	12,9	8,9	10,9	12,5
Number of loads in steering algorithm	0	2	4	1	0

It must be remembered that in large-scale use it would not be possible to determine the threshold values case by case by the DSO. The DSO would suggest a threshold value for each customer. Yet, it would be mainly customer’s responsibility to find the power band that suits best for them. The DSO could develop for example, an online application that determines the threshold value based on the information given by the customer. Customer could enter the information on his power level, electricity consumption, controllable loads, apartment, preferred inside temperature et cetera into the system and it would calculate the suitable threshold value. Only the DSO was allowed to change the threshold value in this pilot. It was technically possible for the customers to change the value but not advisable for the sake of the result of the pilot. The setting-view of the steering algorithm can be seen from the following figure 5.11.

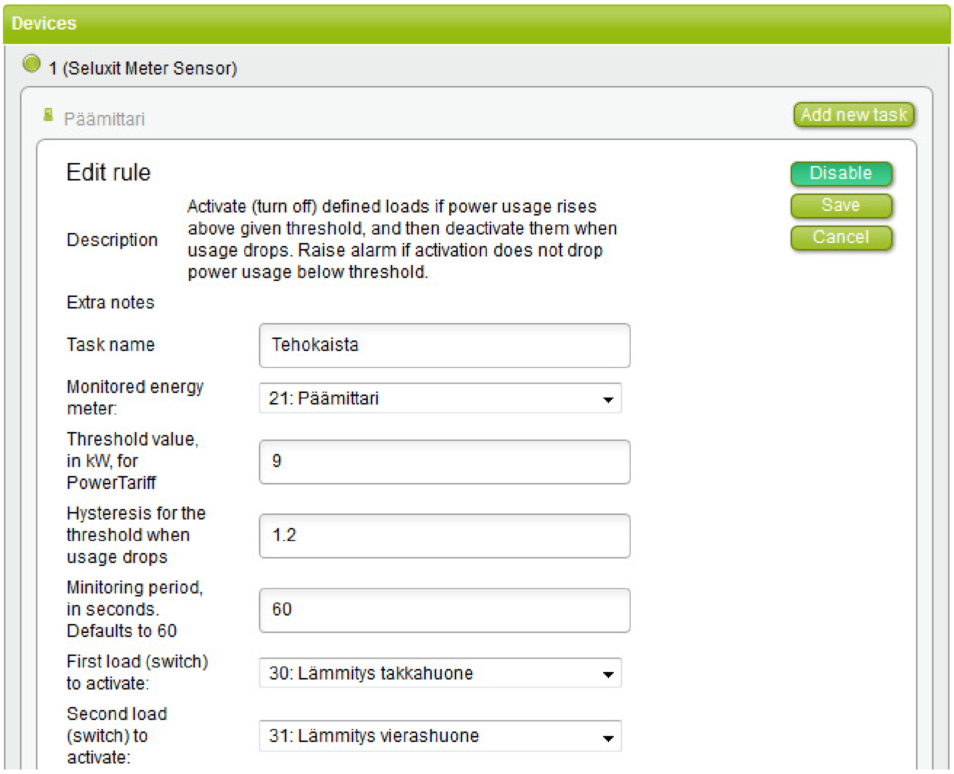

Figure 5.11. *Setting-view of the power band steering algorithm.*

The power band algorithm can be determined in Task-menu. It must be named and monitored energy meter must be chosen. In this pilot the energy meter that was monitored was the main consumption meter. The threshold value was determined in kilowatts. Hysteresis value was the difference between threshold value and hysteresis limit, and it was also in kilowatts. Other option would be to determine the hysteresis value in percent of the threshold value. Monitoring period used in the pilot was 60 seconds but other monitoring periods could also be used. Controllable loads can be chosen from the dropdown menu and they must be set in that order they were wanted to switch off. Even if the customers were not supposed to change the settings or determinations related to the power band algorithm, the menu was designed to be simple to use and customer friendly. HEMS saves all changes done to the hysteresis and threshold values into a file. Also all load activations and other activities related to the algorithm were documented for further analysis.

5.3 Piloting the algorithm

When the steering algorithm was completed it was introduced first in one customer because it was wanted to make sure that it works properly before introducing it to the other customers. Also one addition was made. It was noticed that there was a need to steer so called "inverse loads" that are switched on when the load is wanted to switch off or in other words, reduce the power. When using the temperature drop functionality of the thermostat the load has to be switched on in order to reduce the power. In case the entire heater is steered instead, the load has to be switched off in order to reduce the power. Because both of these loads were used, there was a need to choose whether the load was switched on or off in order to reduce the power. An addition that enabled to choose this was made.

During the first two weeks after the algorithm was introduced the outside temperature varied considerably and as mentioned earlier, the power level is highly depended on the outside temperature. The daily average temperatures of the first week in Tampere region varied from 3,8 to 6,8 degrees Celsius and second week from 1,9 to -18 degrees Celsius so the change was significant. Therefore, the threshold value had to be changed quite often. There was no history data available on minute scale from the previous years but only on hourly scale, so the accurate power level in cold period could not be known. As mentioned earlier, customer billing is based on hourly average powers which are considerably lower than average powers of one minute used in the algorithm. This also means that the threshold value can be exceeded many times as long as the hourly average power is under the power limit when considering the billing.

As there was a need to pilot the algorithm instantly to get results quickly, the threshold value had to be quite strict. As a consequence, the steering algorithm was cutting not only the highest power peaks, but also the smaller daily power increases. In this way the algorithm also helped the customers to save energy, which was not the main intention of it however. The threshold value was changed according to the outside temperature, but because the temperature varied constantly during this time of year, the threshold value was not constant with respect to the power level. Controllable loads were activated from zero to four hours in a day. One significant notice was that even if the temperature drop functionality was activated for several hours the interior temperature did not drop considerably. This means that the comfort of living did not suffer from the load steering.

An example of the loads' behavior is presented in the following figure 5.12. Columns represent the direct electric heating loads of the customer number three and the figure shows how the loads are switched on and off during 25 minutes, each column equaling one minute time period. The threshold value was 4 kW and hysteresis 1 kW at that time. The threshold value was exceeded in 7 minutes and the maximum power was 5,3 kW at 16:43. It can be seen that when the threshold value is exceeded at 16:43, the algorithm starts to switch off loads until the power is under the threshold value at 16:46. At 16:49 also the last load is switched off. Correspondingly, when the power goes under the hysteresis value 3 kW at 17:00, the loads are switched back on one at a time in reverse order.

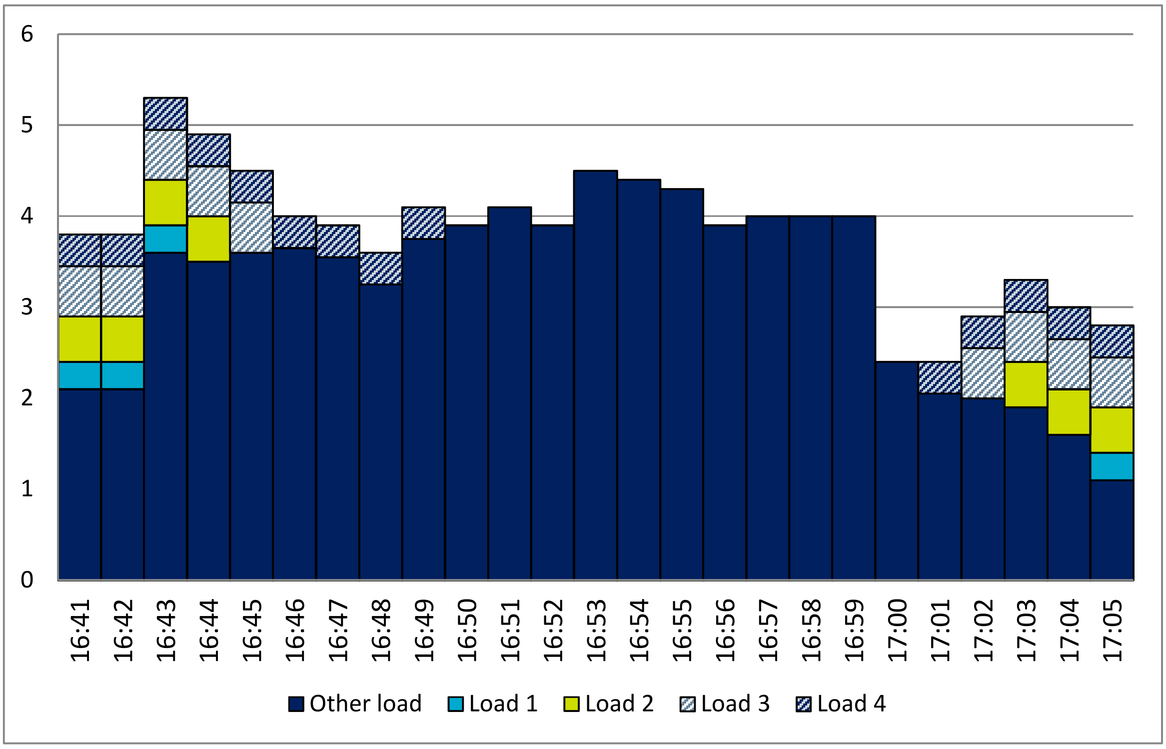

Figure 5.12. *Direct electric heating loads of customer number 3 on 22.11.2012 in kilowatts.*

There is also a priority list presented in the table 5.5. It determines in which order the loads are activated. When the power increases, the temperature drop functionality of the kitchen activates first and bedroom last. Load off means duration of the time that the load has been switched off during that day. The threshold value was exceeded during 28 minutes but the first load was switched off 76 minutes because of the hysteresis. The nominal powers and the average power drop of the loads are also presented in the table 5.5.

Table 5.5. *Priority list of the controllable heating loads and duration of the time that the load has been switched off on 22.11.2012.*

	Load	Load off	Nominal power (W)	Average power drop (W)
1	Kitchen	1:16	600	300
2	Washroom	0:54	550	500
3	Children's bedroom	0:29	2000	550
4	Master bedroom	0:15	800	350

Next the effects of the steering algorithm are introduced individually for each pilot customer. The most important thing that was investigated was weather the power peaks reduced and the power level changed. It was also investigated in which situations the alarm messages were sent to customers and how the customers reacted on them.

Customer 1

Power peaks from the sauna stove could be halved with the coupling that switched off the upstairs' electric heating when the electric sauna was turned on. However, as could be seen earlier from the figure 5.5, customer's duration curve of the yearly power consumption was quite steep and large power peaks occurred. The threshold value varied between 13 and 23 kW, which was the highest threshold value of all pilot customers. All of the large power peaks were caused by the hot water boiler and electric storage heating. Both of these were on spot-price based steering so these power peaks occurred during night-time. There were not any controllable loads in the steering algorithm so as a result, the largest power peaks could not be reduced. The only functionality of the steering algorithm was the alarm message sent to customer when the threshold value was exceeded. But as the night-time power peaks were really high, the threshold value had to be high so that the alarms would not be sent constantly. Because of this, the power did not exceed the threshold value during daytime and the customer did not receive messages of the high power at times when he could have done some actions to decrease the power.

Customer 2

This customer had two controllable heating loads in the steering algorithm. The threshold value varied between 6 and 12 kW depending on the outside temperature. Nominal powers of the similar heating loads were 1000 W, meaning 2000 W together. It was investigated that when the loads were activated, the total average power drop was 1640 W. Hence, in this case the load control potential was 80 % of the nominal power. Following results could be achieved in the power level decrease.

- Average hourly power decreased by 4 % in one weeks' time period when the average outside temperature was 3 degrees Celsius.
- Average one minute power decreased by 3 % in one weeks' time period when the average outside temperature was 3 degrees Celsius.
- Daily peak powers decreased by 1,2 kW. This equals to 18 % when comparing to the former peak powers. The decrease was the same in hour and minute scale.

Customer 3

This customer had the largest amount of controllable loads in the steering algorithm so the best results in reducing the power level could be achieved. Controllable heating loads were steered with the temperature drop functionality so first it was wanted to investigate how much the power reduced when the temperature drop was activated. The consumption data was analyzed. However, as can be seen from the figure 5.13, the loads in this household switched on and off at an extremely fast pace so the power drop could not be seen straight from the consumption profile. The power drop was estimated from one minute average powers. Several minutes' values before and after the load activation were compared. The nominal powers of the heating loads were known and the actual power drop was compared to that. The result was that the actual power drop is approximately 45 % of the nominal power. So in case of this customer, the total actual power decrease potential is 1700 W. It must be remembered that this is only the average load control potential and the potential varies greatly depending for example on the inside temperature. If the fireplace has been used and the electric heating has not been needed at the full power, the power drop is very small when the temperature drop functionality is activated. Instead, in cold weather when the fireplace has not been used and the temperature drop functionality is activated, the power drop can be momentarily quite near to the nominal power. In this household, the fireplace was used very often.

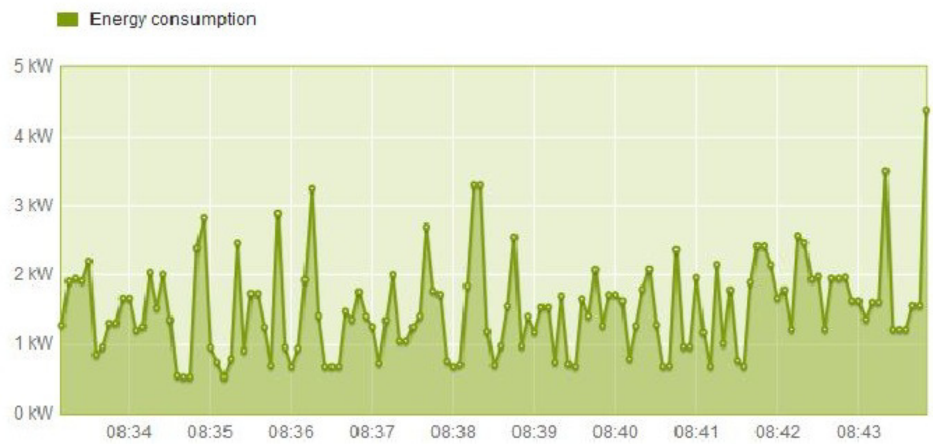

Figure 5.13. *10 minute time period from the main consumption data of customer 3.*

Next, changes in the power peaks and power level were investigated. Both colder and warmer time periods were wanted to investigate as well as both powers on one minute and hourly scale. Following three different observation periods were investigated. The powers of these periods were compared to the powers of time periods when the steering algorithm was not used. Observation periods had the same length and average temperature. Results of this analysis are introduced next.

- Average hourly powers decreased by 11 % in three weeks' time period at which time the average outside temperature was -8,5 degrees Celsius.
- Average hourly power decreased by 9 % in one weeks' time period when the average outside temperature was 4 degrees Celsius.
- One minute maximum powers decreased by 5 % in one weeks' time period when the average outside temperature was 4 degrees Celsius. The steering algorithm monitors the one minute average power and the controllable loads are activated only when threshold value is exceeded. Hence, there is a one minute delay in the steering algorithm and the total power can be very high for one minute

before the load activations starts to work. If the powers of these minutes before the load activation are not taken into account, the reduction in maximum powers on minute scale is 11 %. This means a decrease of 0,6 kW from the maximum power.

Also the timing of the power peaks was investigated. Customer have night-time distribution tariff so the hot water boiler is steered to be used during night-time hours. As a consequence, the hourly night-time powers are 18 % higher than daytime powers. Because of this, most of the load activations occurred also in night-time. Although, the difference between night and daytime powers was not as high as the customers number one and five had, and load activations happened often in daytime too. The threshold value varied from 4 to 9 kW.

Customer 4

This customer had one controllable load in the steering algorithm and its power was approximately 520 W. This underfloor heating was turned on around half of the time in few hour periods. The temperature drop functionality was not used but the entire heating was steered. The threshold value varied between 7 and 9 kW, and with values like this the load was activated from 1 to 5 times in a day. Load was switched off usually between 1-30 minutes at a time. Three quarters of the load activations occurred when the underfloor heating was turned on, so in most cases the load control potential was 520 W. Daily peak powers decreased only by 250 W.

Customer 5

In order to reduce the power level, the DSO’s night-time delay was removed from the hot water boiler. Hence, the hot water boiler switched on 1-60 minutes earlier. In this way the time when both hot water boiler and electric storage heating were switched on at the same time was tried to minimize. However, this action did not reduce the night-time power peaks considerably, because both reserving heating loads were still switched on a significant amount of time at the same time. Threshold value varied between 10 and 15 kW.

There were not any controllable loads so the only functionality of the steering algorithm was the alarm message sent to customer when the threshold value was exceeded. However, most of the power peaks occurred during night-time because of the reserving heating loads, so there were not any actions that the customer could do to decrease the power. Moreover, as the customer received the alarm messages during night-time, e-mail messages were used instead of SMS message. This probably diminished the effect of the alarm messages but was a necessity because of the inconvenient night-time SMS messages.

User experience

Customer feedback was collected during the pilot study. The overall user experience of the steering algorithm was quite positive. Customers that had controllable loads in the steering algorithm said that the load control actions of the steering algorithm could not be noticed for the most of the time. In rooms where the temperature drop functionality of the radiators was used the room temperature did not decrease and the customers could not notice any change. Only one customer said they had noticed that the temperature had decreased during one week when the threshold value had been exceptionally strict and outside temperature lower than -10 degrees Celsius. The steering of the underfloor heating could be noticed better. If the power had been high for few hours and the loads activated, the customers could feel that the temperature of the floor was lower than normally.

All customers were receiving alarm messages, but they felt they were not that useful. Many customers were receiving the messages during night-time and in other situations when they could not decrease the power. One customer mentioned that messages should be sent only in extreme peak power situations, not daily or weekly.

Customers also had some development ideas of the steering algorithm. One customer suggested that there could be some preconditions in the load activations. Controllable loads could have some conditions that would limit their activation, for example a minimum inside temperature limit that prevents the load to activate if the temperature is too low. Another possible condition could be time limits, for example that the underfloor heating of the washroom cannot switch off during 6.00-7.30 when people are usually using the shower. One customer suggested that the algorithm could consider the outside temperature in determining the threshold value. He also proposed that in this case the messages would be sent only when the power has been high with respect to the outside temperature.

6 EVALUATION OF THE POWER BAND CONCEPT

In the future, there will be some significant changes in the electricity market that will affect to the future tariff structure. Changes in the operational environment drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level for the DSO. The power band concept is considered to be one of the best options for the future network tariff and it was introduced in chapter 4. Future development of smart grids and energy markets allow market actors to develop new possibilities around demand response and load control. It is likely that different HEMS solutions become more common in near future. In the pilot study, a HEMS solution combined with the new steering algorithm was introduced. The steering algorithm was developed to support the power band tariff.

Pilot study enabled to recognize some issues that should be considered when designing future network tariffs and Home Energy Management Systems. These are discussed in chapter 6.1. In chapter 6.2 potential benefits for the DSO are evaluated. Chapter includes calculations of how large power reductions could be achieved by using HEMS with the steering algorithm. Also an analysis is made on how the load control could benefit the DSO in purchasing of network losses. Finally, one possible operation model around HEMS is briefly introduced.

6.1 Utilizing HEMS with steering algorithm in the power band scheme

The power band concept was introduced earlier in this work and the steering algorithm was developed based on that information. The purpose of the pilot study was not only to investigate the steering algorithm, but also the entire power band network tariff concept. However, all pilot customers had night-time distribution tariff throughout the pilot which set some limits for the analysis, as the reserving heating loads could not be used outside the night-time hours. In some cases it would have been beneficial if some of the reserving loads could have been used also outside the 22:00-07:00 night-time hours.

In chapter 6.1.1 the pilot customer number 4 is used as a case study as the power band concept is analyzed. Conclusion of the most desirable tariff model is introduced at the end of the chapter. After that the power band model is discussed from the customer billing point of view. There are also some technical challenges of the HEMS and development needs of the steering algorithm discussed in chapters 6.1.3 and 6.1.4.

6.1.1 Case study of determining the band size and excess usage events

In the original power band concept, introduced by (Partanen et al. 2012), it was assumed that the size of the band is determined by the customer's highest hourly average power of the year and is constant throughout the year. However, the household customer with electric heating is consuming electricity significantly more during the wintertime as shown in the following figure 6.1. There is a yearly hourly power consumption of a household customer 4 with direct electric heating presented in the figure. The household is one of the customers participating in the HEMS pilot introduced earlier and the data is from year 2011 when the power band algorithm was not used. The consumption varies considerably according to the outside temperature. Hence, the power band would usually be determined according to the winter's coldest days. In the case of 3 kW steps and the band scaling from the table 4.1, the band would be 11 kW for the customer in the figure because his maximum power of the year is 10,9 kW. This would not be favorable because so big band will not give any incentive to decrease the power consumption. The incentive to decrease the power would be limited only for the coldest winter months and there would not be any incentive during the rest of the year, because the 11 kW limit is so high that it is almost impossible to reach even in the winter.

If taking into account the excess usage events introduced earlier, the situation with the lack of incentive will not become much better. If the number of allowed excess usage events is 15 for 8 kW, as suggested earlier, the band size could not be reduced to 8 kW, because 8 kW is exceeded 37 times. When considering the other option, excess usage event fee, we get the same result that the band could not be reduced to 8 kW. 8 kW is exceeded during three months; hence the band of 8 kW would not be possible. The number of allowed excess usage events should be significantly larger in order to achieve band sizes that encourage people to lower the power level.

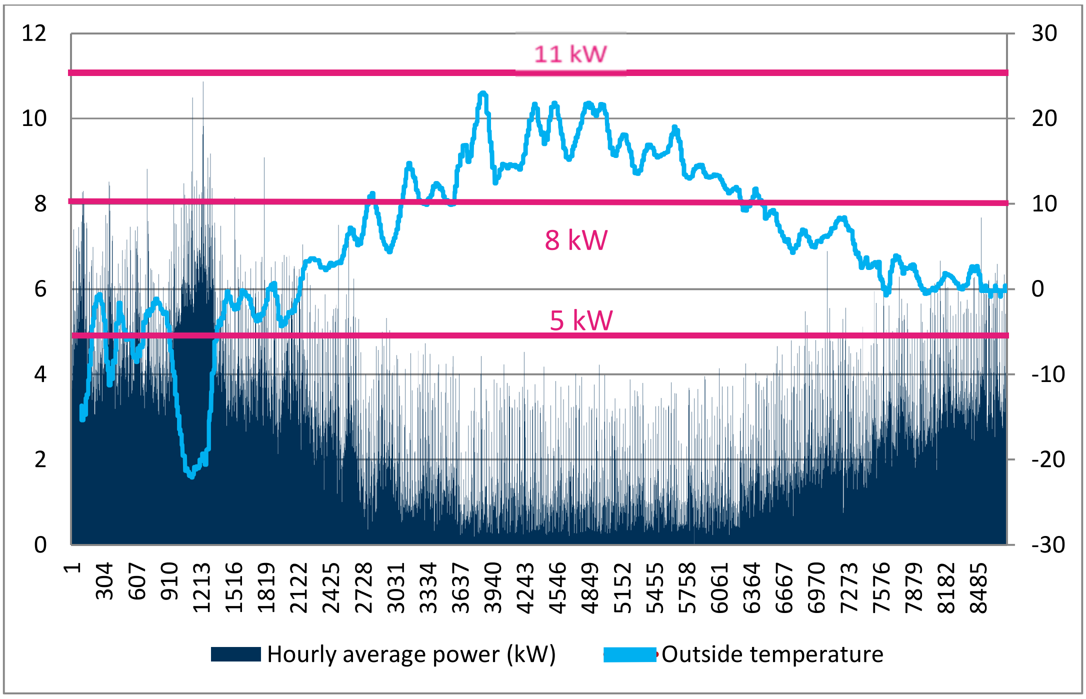

Figure 6.1. *Yearly power demand of customer 4 with electric heating and daily average temperature. The average hourly power is in kilowatts and temperature in Celsius degrees.*

However, it must be remembered that in this case the power band tariff has not been in use and the customer has not done any actions to limit his power consumption. Customers would always have an opportunity to reduce the power consumption and affect to his size of the band, but it would not be compulsory in any way. In this case, the customer would have been able to reduce his peak power and stay under the 8 kW limit quite easily only by paying attention to his power consumption. If taking into consideration the effect of the steering algorithm, result is that the 8 kW limit would have been achieved. The customer had one controllable load of which power was 0,55 kW. Based on the pilot study, this controllable load combined with the alarm message of the steering algorithm helps the customer to achieve the 8 kW power band. Although, the 15 allowed excess usage events are needed.

One option could be to determine the power band based on the 10th or 20th largest power of the year. When the consumption data of 179 night-time distribution customers were investigated, it was noticed that maximum powers were few kilowatts larger than rest of the powers. On average, the difference between the maximum power and 10th largest power of the year was 1,6 kW. The same difference between the maximum power and 20th largest power was 2,1 kW. Consequently, if the band would be determined based on the 10th or 20th largest power of the year, the excess usage events would be more likely but there would be more incentive to reduce the power level. The 20th largest power of customer 4 is 8,4 kW which does not allow the band to drop to 8 kW. Only 37th highest power is less than

8 kW. The size of the 10th and 20th highest powers vary greatly in different customers, so this would not be the most favorable way to determine the band size for all customers. It must also be remembered that the largest maximum powers are quite easy to reduce only by paying attention to the power level. So along with the introduction of power band, it is likely that the number of power peaks will reduce.

Even though it would be possible to reduce the size of the band into 8 kW, the problem with the lack of incentive still exists. Especially during summertime there is no incentive at all. One possible solution could be separate bands for summer- and wintertime. Then the power peaks caused by the cold weather would not affect to the summertime power limit. Figures 6.2 and 6.3 show how the maximum and average powers vary monthly depending on the time of year. The powers are hourly average powers of 179 Elenia Verkko Oy night-time distribution customers. Winter months from November to March are marked with darker color and it can be seen that the maximum powers are higher during wintertime. On average the difference between summer and winter maximum powers is 2,6 kW. The same difference in average hourly powers is 1,8 kW. Fingrid, the enterprise which takes care of the nation-wide high-voltage grid, charges a consumption fee for the grid service for DSOs. The consumption fee is specified separately for winter months and for other times. The winter time fee is significantly larger than the other time fee which also supports the model of two seasonally varying fees. However, from the network dimensioning point of view, only the highest power peaks have an impact and there is not that much need to limit the power level in summer as the overall power level is usually significantly lower.

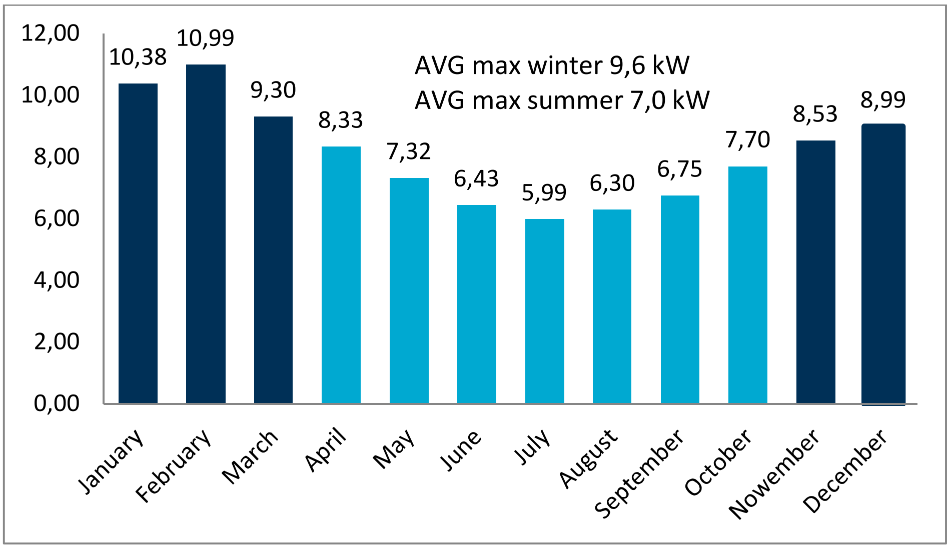

Figure 6.2. *Average hourly maximum powers of 179 night-time distribution customers.*

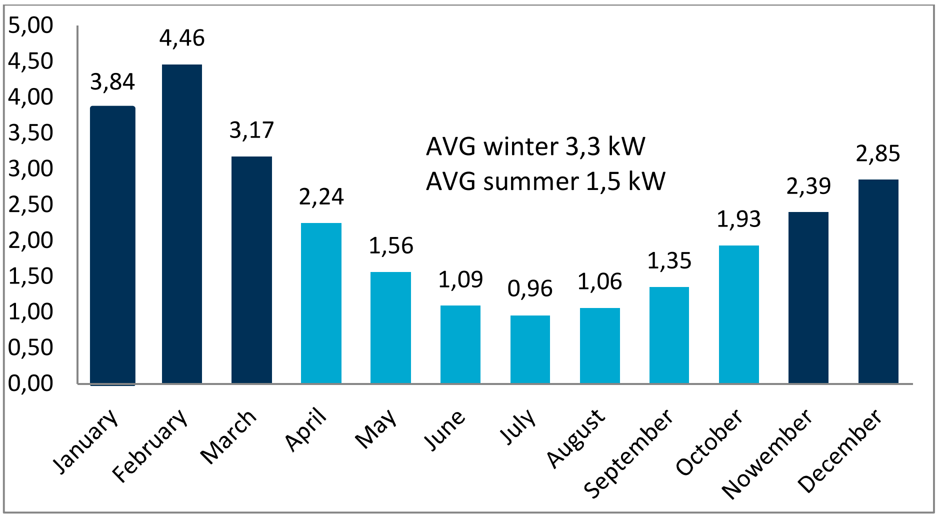

Figure 6.3. *Average hourly powers of 179 night-time distribution customers.*

Figure 6.4 shows that the maximum powers of the pilot customer number 4 vary considerably between different months but the division to winter and summer months is not that straightforward. Maximum power of November is lower than maximum powers of April and October that are usually considered as summer months. There are also great differences between different years. However, when investigating the maximum monthly powers of the five pilot customers, it can be seen that the powers from May to September are clearly lower than in other months. This means that if using separate summer and winter bands, it should be considered how the months are divided between summer and winter time. If April and October would be considered as winter months, it would enable the summer band to be smaller and this way bring incentive to limit the peak power in summer time too. In case of customer number 4, the summer band would be 5 kW when categorizing April and October to winter months. Now the customer would have to reduce the peak power in May and during rest of the months he is already under the power limit. The power limit is not that large, however, that there would not be any incentive to monitor the power level throughout the summertime. With help of the algorithm, it is possible to reduce the power from 5,3 kW to less than 5 kW in May.

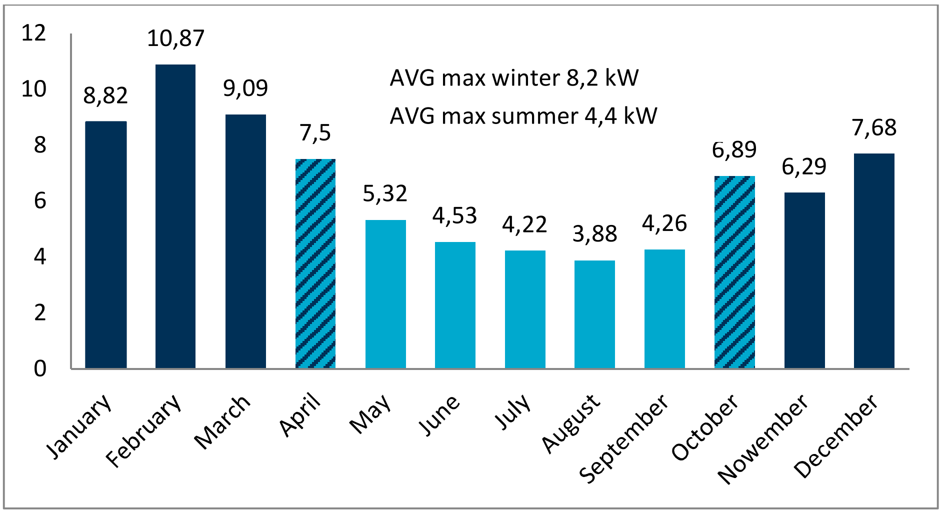

***Figure 6.4.** Maximum monthly powers of pilot customer number 4.*

Other option is that the band changes monthly according to the power demand. This way the customer would have incentive to decrease the power demand every month even if he has months when the demand has been higher. Especially in Finnish climate where the temperature varies significantly during the year, it is challenging to determine only one power limit. If the band would be determined separately to each month, there would be no need for excess usage event fee. This model would allow customer to use bigger amount of power in some period without removing the incentive to limit the power for the rest of the year. Drawback of these alternatives is that the monthly paid distribution fee can vary considerably which is not desirable either on customer's or DSO's point of view. DSOs expect that distribution tariffs provide predictable and secure income formation. In addition, the more complex the tariff structure is the more work it causes to the DSO, for example with customer's billing. One of the basic ideas of the power band introduced by (Partanen et al. 2012) is that the monthly fee is constant throughout the year and this is in contradiction to that. In addition, if the band is determined each month according to the maximum power, customer knows the size only afterwards. If the band size is constant, customer knows the size beforehand. This probably increases the motivation to control the power because there is a certain level which should not be exceeded.

In both, one constant power band throughout the year and seasonally varying band models, there is still a need to find a way to handle the excess usage events. It is important that the power band provides real incentive to control the power level and then, regardless of the load control methods and other ways to limit the power, it is very likely that there will be situations when excess usage events happen. That is why it is important that the customers will not be punished straightaway for moderate excess usage events. From the customers' perspective and for the sake of flexibility of the power band pricing, it would be justified to allow the customer to exceed the band. Two ways to handle the excess usage events were already discussed, allowed excess usage events and excess usage event fee, but as stated above, there are some problems related to them. One option would be to apply the Critical Peak Power pricing model for the excess using events. This would mean that the excess usage events would be allowed during times of extreme system peak, but customer would have to pay an extra fee for the excess usage events. Critical Peak Power excess usage events would be restricted to a small number of days. These critical peak days would be limited about ten days per year. The days in which critical peaks occur are not determined in the tariff, but dispatched on relatively short notice as needed. This model would eliminate the effect of the coldest winter days on the peak powers by allowing customers to excess the band during those days. When determining the power band, the powers that have occurred during the critical peak days would not be considered. Customers are still encouraged to reduce the power in these hours by collecting a high-level fee for the powers that excess the power band during critical peak power days. It was investigated that during the 12 days in which the amount of transferred energy was at its largest in Elenia Verkko Oy's area, 37 % of the customers achieved their maximum power of the year. It can be assumed that the other highest powers are reached during these days as well. It was also investigated that 25 % of the customers achieved their maximum powers during the same 5 days and 39 % in 12 days. These days when the maximum powers occurred and when the amount of transferred energy was at its largest were mainly the same days. However, it must be remembered that 63 % of the excess usage events happen outside of this extreme system peak so there might be a need to observe other excess usage events as well. On the other hand, the excess usage events can be controlled somehow in practice by the customer. If customer is not willing to limit the peak power in these situations, he would have to pay more.

Household customers' possibilities to affect to the excess usage events vary considerably among different customer groups. The more controllable loads customer has, the better opportunities he has to achieve smaller band sizes. Detached house customers usually have more loads than customers in apartment buildings and row houses have. Usually there are centralized heating systems in apartment buildings and row houses, so the largest loads are kitchen and sauna stoves. These loads are used when it best suits the customers and the control of the power level is not possible. Hence, these customers have very small possibilities to reduce their power level. On the other hand, even when a great number of loads are switched on at the same time, the power is not very high because loads are small, and this will keep the distribution fee low. Because of the unequal possibilities of different customer groups to control the power level, it is important that the allowed excess usage events are used.

From the customer point of view it is important that the power band model is as simple as possible and easily understandable. Also for the sake of the customer billing, the simplicity is important. Two essential observations were made from the previous analysis of the band determination and excess usage events. First, in order to avoid the lack of incentive during summertime, separate bands for summer- and wintertime are needed. Secondly, it is important that the band is allowed to exceed for some reasonable times. The best way to determine the band size would be to determine first the band size according to the maximum power of the last summer or winter season and then investigate if the smaller sizes are possible within the allowed excess usage events. However, DSOs cannot individually investigate what band sizes each customer could achieve, so this would have to be on customer's responsibility.

The power band model suggested next is also based on the previous analysis. Separate summer and winter bands would be used and summer season would include months from May to September. The band size would be determined according to the maximum hourly power of the previous summer or winter season. Allowed excess usage events would be applied and the number would be constant regardless of the band size. 30 allowed excess usage events per winter season and 10 for summer means altogether 40 events in a year, which should be enough to eliminate the largest power peaks. This model sets the customer's activity in an important role as the DSO would determine the band according to the maximum power. Customer would have an opportunity to ask the DSO to change the band size for one size bigger or smaller each time the season changes. History data of each customer is available in online service, so the customers would be able to optimize the band size based on that information. However, it is needed that the data available in online service would be presented from the power band point of view. In this model the customer would be able to determine and change the threshold value of the steering algorithm by himself. This gives customers a possibility to change the threshold value as often as they want which would help them to find the most suitable value. DSO would calculate the excess usage events and if the allowed number is exceeded, the customer would be transferred to a larger band by the DSO. Downside of this model is that there would probably be customers that have oversized band caused by the lack of interest towards the network tariff. The steps of 3 kW would be used, but when the customers are familiar with the band and have more HEMS solutions that help to control the power level, steps of 2 kW could be considered.

6.1.2 Customer billing

One of the most important things from the customer point of view is the customer billing. The bill must be clear and easy to understand, but still provide all the information required. The information provided on the bill must help customers to understand the formation of their tariff fee. In the power band tariff the band size is determined based on the maximum hourly power of the year. The band fee would be constant €/kW. In the following table 6.1 there are pilot customers' maximum powers of the year 2011 and power bands that are determined based on that. Present yearly night-time distribution fees are also in the table. Power bands that could be achieved with the help of the steering algorithm and with the introduction of the new tariff are also presented. Although the largest decrease in hourly peak power was 1,2 kW, it was evaluated that if taking into account the allowed excess usage events and the real monetary incentive that there would be if the power band would be introduced, three pilot customers could achieve lower power band size. In order to further investigate how small band sizes customers could achieve, more information about the steering algorithm's effect on the power level is needed throughout the year.

Table 6.1. *Information on the pilot customers' distribution fee and power band limits.*

	Customer 1	**Customer 2**	**Customer 3**	**Customer 4**	**Customer 5**
Yearly consumption (MWh)	29,3	24,7	19,9	21,1	21,6
Maximum power (kW)	26,1	12,9	8,9	10,9	12,5
Present yearly night-time distribution fee (€)	**1460**	**1320**	**1120**	**970**	**970**
Power band according to the maximum power (kW)	29	14	11	11	14
Power band that could be achieved with the steering algorithm (kW)	-	11	8	8	-
Price of the power band (€/kW/month) with similar distribution fee	**4,2**	**7,9 / 10**	**8,5 / 11,7**	**7,3 / 10,1**	**5,8**

The price of the power band is calculated in the bottom row. The calculated €/kW price is determined in a way that the yearly distribution fee would be the same as the present fee. The calculated €/kW band price is for one month. The band prices vary from 4,2 to 11,7 €/kW depending on the maximum power. However, the price cannot be calculated based on individual customers but it must be determined in the entire distribution network level. The price of power band would be determined based on the network operation costs, that is, the regulated revenues and volumes of subscribed power. The calculated values show that the variation is great and if the power band would be introduced, customers' distribution fee would probably change significantly. Someone's fee would increase and someone's decrease. Therefore, it is very important that customers are informed properly and they feel that they have real opportunities to affect to the band size and consequently, to the distribution fee.

6.1.3 Technical challenges of the HEMS combined with the steering algorithm

As discussed earlier, finding a fifth customer to the pilot was surprisingly difficult. Customers with electric storage heating were not willing to include loads like lighting, consumer electronics and sauna stoves to the steering algorithm. Customers with direct electric heating had quite positive attitude towards the controlling of heating loads, but there were some technical challenges related to that. The preferred method to steer the heating loads was to steer the temperature drop functionality of the thermostat. Quite a few thermostats have temperature drop functionality, especially the newer ones, which can be steered with the HEMS. However, the more automation the heating system contains the more difficult it is to steer with external equipment. Many heating systems include steering opportunities themselves, which cannot be steered with HEMS. Moreover, many customers have replaced direct electric heating with other heating methods, like heat pumps, which cannot be steered with HEMS. Steering opportunities of different heating systems improve the energy efficiency and comfort of living, while also bringing competitive advantage for the company that manufactures these systems. However, from the DR point of view, it would be extremely important to include a possibility to steer the device with external equipment. This is one requirement for large-scale load control that enables DR. If it is not possible to control the most common loads in households with external equipment, such as HEMS, large-scale DR actions are not possible. Therefore, cooperation with different equipment manufacturers and HEMS providers is needed. Example of this kind of steering possibility is a simple home/away switch that can be steered with outside equipment like HEMS.

In many cases the customers were not aware of the functionalities, steering possibilities, sizes or installations of their heating systems and other household devices. If they are interested in investing HEMS, they must consult both an electrician and HEMS expert, who have to visit the customer before it can be known what functionalities can be added to system. Only after that the installations can be planned and an installation visit be done. This increases the costs of HEMS considerably. One option would be that the HEMS provider would have a database that would contain information about the most common devices in Finnish households. The information needed is whether the device can be steered with outside equipment, is there any limitations on load control and how the devices are usually installed. With the help of this information, it could be possible to find out what functionalities can be added to the system without extra visits and only one installation visit would be needed. However, the amount of different household devices is huge and it would be a great effort to create that kind of database. In addition, household devices can be installed in multiple ways so the final certainty of the compatibility with HEMS is reached only on site.

The most potential controllable loads are different direct electric heating units. They are usually the largest electrical appliances in households after sauna stoves and kitchen stoves. Other loads that could be steered without losing the comfort of living are for example ventilation and air conditioner. Also freezer could be steered if the reliability of HEMS is large enough. Charging of the electrical vehicles could also be steered by the algorithm.

One way to achieve better steering possibilities is to consider HEMS during the construction of new buildings. Although it is completely possible to install HEMS with load control functionalities for the most of the existing households, the most comprehensive and effective solution would be achieved if considering the HEMS already in construction stage. This way all loads that are wanted to include to the system could be equipped with suitable steering relay. Consequently, the more loads can be added to the system the better results can be achieved. Focusing on the new households would be beneficial also because in order to accomplish any effects, a large number of customers must be equipped with HEMS in a certain area. Large-scale effects to the power level might be easiest to achieve in new residential areas, where a large number of customers could be equipped with HEMS during construction. These new customers would also be easiest to reach because they are in contact to the DSO during the connection opening process. DSO could inform them at the same time about the HEMS concept. The promotion of a new concept is in a significant role, and the DSO must carefully prepare an information campaign. It is very important that the purpose of such a service is clearly introduced to the customers from the very beginning.

Consumption data of 179 Elenia night-time distribution customers and 205 new Elenia customers were compared. The customers in new customer's group had the general distribution tariff. Customers were grouped to different power bands according to the maximum power of the year. Scale of 3 kW was used in power band. Division to power bands can be seen from figures 6.5 – 6.6. There are no big differences in largest maximum powers of these customer groups, and in both groups the largest band size is 20 kW. The most common band size of the night-time customers is 11 kW including 39 % of the customers. For the new customers, the most common band size is 14 kW including 44 % of the customers. Consequently, it can be seen that the power level is slightly higher among the new customers than among the night-time customers, although the average yearly energy consumption is significantly lower in new customers' group. It can be also noticed from the consumption data that the power peaks are larger among new customers. In night-time distribution customers, the average differences between maximum power and 10^{th} and 20^{th} highest powers are 1,6 and 2,1 kW, respectively. Corresponding numbers in new customers' group are 2,1 and 2,8 kW, respectively. As the power peaks have become larger in recent years, it can be assumed that there would be a great potential to reduce the power level among new customers. HEMS solutions are needed in order to get results.

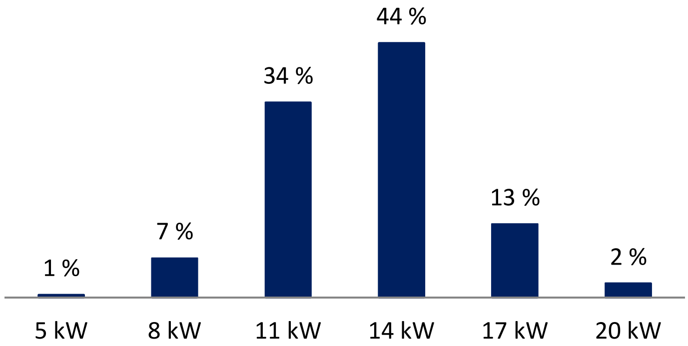

Figure 6.5. *Grouping 205 new household customers to different power bands according to the maximum power of the year. Scale of 3 kW was used in power band.*

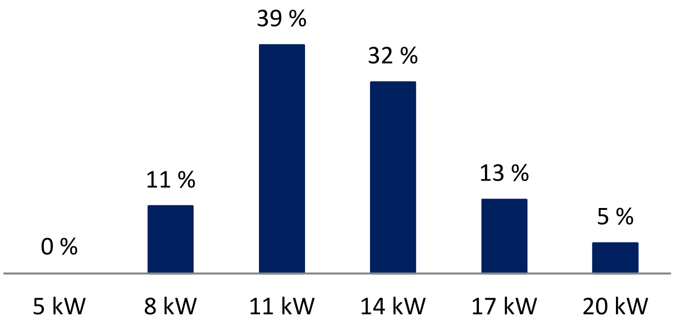

Figure 6.6. *Grouping 179 night-time distribution household customers to different power bands according to the maximum power of the year. Scale of 3 kW was used in power band.*

Where the new customers are the most potential customer group for the HEMS concept, the customers in apartment buildings and row houses have the smallest potential. HEMS needs the total energy consumption data from the electricity meter and in most of the apartment buildings and row houses the electricity meters are outside the apartments from where the data cannot be transferred wirelessly to the HEMS unit. These households also have centralized heating system, like district heating, so the load control potential is very small. That is why the HEMS could be marketed only on customers living in detached houses.

6.1.4 Development needs and opportunities of the steering algorithm

The main objective of the pilot study was to develop the first version of the steering algorithm and to pilot that in customers. The algorithm was quite simple and during the pilot some development needs and opportunities arise and they are introduced next.

Development ideas that the pilot customers suggested were already introduced in the end of the chapter 5.3. The most important ideas were related to the conditions of the load activations. Another development need that came out was the consideration of the outside temperature in the threshold value. As the power level is highly dependent on the outside temperature there would be a need adjust the threshold value according to the temperature. If the HEMS would receive weather forecast the threshold value could be adjusted for example by 10 % according to the outside temperature.

One small problem in the beginning of the pilot was the determining of the hysteresis values as the powers of the controllable loads were not known. These powers were not constant so the most optimal hysteresis value could not be used. The system could determine the power drop each time the load is activated and utilize this information when switching the loads back on.

In the future it is important that more different types of loads can be added to the system. Also other ways to extend the system are needed to develop. Functionality that could be developed is the possibility to steer the loads to switch on when the power level is low. For example, some reserving heating loads could be used during the daytime when customers are not home and the power level is low. This could decrease the night-time power level.

The algorithm removes the responsibility of steering the loads from the customers and does it automatically. It is important to remember that the activity level of the customers usually diminish after a while so the automatic steering is in essential role. The easier and more automatic the use of the steering algorithm is, the better results can be achieved.

Added to the development needs of the steering algorithm that were described above, one additional opportunity around HEMS is now introduced shortly. In power outage situations the HEMS could enable so called "emergency electricity" for the customers equipped with HEMS. This necessity electricity would provide a small electricity supply for the customers which would enable only the most crucial electrical devices functioning in the households. The electricity supply would be handled with reserve power or energy storages that are placed in the area. The necessity loads would be determined into the HEMS and the DSO would set the maximum limit for the power. The necessity mode would be activated in case of a power outage. In this way functioning of the most crucial electric devices could be ensured even during the power outages.

6.2 Potential benefits for the DSO

DSO could benefit greatly from the large-scale use of HEMS-solution that enables demand response and smaller power level. HEMS-solutions usually help customers to reduce their energy consumption which decreases the DSO's income with current tariff structure. Also customers' small-scale electricity production will reduce the DSO's income in the near future if the tariff structure does not change. However, with suitable network tariffs and HEMS-solution it is possible to achieve lower peak powers which eventually affect positively on the costs of the DSO. It must be remembered that the peak power reduction must be permanent to benefit the DSO. First, the effect of the steering algorithm on the peak power need is examined. Results from the pilot study are applied and an estimation of the reduced peak power level that could be achieved is made. After that it is investigated if there are any conflict situations in load control actions of the algorithm between the DSO and retailer. Also an analysis is made on how the load control could benefit the DSO in purchasing of network losses.

An important incentive for the DSO to try to limit the power level is the positive effects of the load control on the distribution network dimensioning. If the load control actions of the steering algorithm are implemented on a large-scale, the effects can be utilized in network design. The reduced power level would relieve the stress on the distribution network while also temporarily postpone the need for network renovation. The largest benefits could be achieved in problematic supply areas, for example in a certain feeder, where the power is already near the maximum level. Load control can cause significant savings as the network renovation can be postponed. Reductions in the peak power have positive effects also on the load of the main transformer which can prevent the DSO from new investments in a long term. In addition, network losses can be reduced. That is why it is important to include the demand response and load control into the network dimensioning and investment planning.

The load control potential and decrease in peak power that could be achieved with the steering algorithm are collected to the following table 6.2. The results of the pilot study were discussed in more detail in chapter 5.3 and only the most important information is collected to the table. Based on that information the load control potential of typical household customers was evaluated. The sizes and numbers of the controllable loads varied considerably among different customers. Also number of the pilot customers was quite small so the evaluation of the load control potential was difficult. However, it can be estimated that if the number of the controllable loads per customer is at least two the average load control potential should be at least 1,3 kW. If the number of controllable loads is greater than two the average load control potential can easily be 2 kW. It was also estimated that if considering the HEMS already under construction the potential could be more than 2 kW. It must be remembered that the load control potential is the average power decrease that can be achieved. At times when the load control actions are executed, some customers may have significantly larger and some smaller potential but on a large-scale load control these fluctuations are compensated.

Table 6.2. *Summary of the pilot customers' the load control potential.*

	Customer 1	Customer 2	Customer 3	Customer 4	Customer 5
Number of controllable loads	0	2	4	1	0
Average load control potential	0	1,64 kW	1,7 kW	0,5 kW	0
Decrease in peak powers	0	1,2 kW	0,6 kW	0,25 kW	0

It is examined how the estimated load control potential could decrease the maximum power in certain supply area. The load profile of the main substation feeder where the customer 1 is located was investigated. The power situation is quite strict in that certain feeder and the maximum power of the feeder was 2100 kW in year 2011. This power occurred during cold winter day. Table 6.3 provides information of what kind of customers are located in that feeder according to their distribution tariffs. As the numbers show, there are a lot of small consumers with main fuses of 25 A.

Table 6.3. *Distribution tariffs of the customers that are located in the feeder. (Modified from Aalto 2012)*

Tariff type	Fuse size (A)	Number
General Distribution	1x25	32
	3x25	327
	3x35	20
	larger	8
Night-time Distribution	3x25	146
	3x35	27
	larger	3
Seasonal Distribution	3x80	1
Demand Tariff	-	5
Total customer number		**569**

All pilot customers had night-time distribution tariff so there is no information on what the load control potential of general distribution customers could be. That is why only 10 % of the general distribution customers were included to the calculations. When considering the night-time distribution customers, a cautious estimate was made that 50 % of the customers would be equipped with HEMS. This would mean that 38 general distribution and 87 night-time distribution customers of the overall customer number of 569 would be equipped with HEMS. If the load control potential of individual customer would be 1,3 kW the total load control potential in this feeder would be 163 kW. This corresponds to 7,8 % of the maximum power of the feeder. Consequently, it can be said that even with moderate load control actions a significant effect on the feeders power level could be achieved. This result looks encouraging but more research about this topic is needed as only one feeder was investigated in the previous example. There is always some amount of dispersion in the peak powers of the customers, so it should be further examined what is the total load control potential during the maximum power situation of the feeder.

Next, it is investigated if there are any conflict situations in load control actions of the algorithm between the DSO and retailer when the spot price is high or low. Demand that is optimized based on either generation or distribution only may be non-optimal to the other party. The market price based DR could shift the consumption from the peak price hours to the hours when the consumption in a certain feeder is already at the highest level which can cause problems to the DSO. On the other hand, load control actions that are executed by the DSO can cause problems for the retailer. Large-scale load control actions can disturb the retailer's power balance between the electricity procurements/production and the consumption/sales. This can cause significant damage to the viability of the retailer's business. (Valtonen 2012) Because of this, it was wanted to find out whether the load control that is based on the steering algorithm causes any inconveniences for the retailer.

This analysis was carried out for the day in which the area spot-prices in Finland were high during the pilot study. Spot-price of the electricity is typically at its highest when the overall electricity consumption is large, and correspondingly, the cheapest prices are achieved when the consumption is small. The 5th of December was chosen for the analysis, and there are the highest and lowest area prices of that day and hours when they occurred presented in the table 6.4. The highest spot-price of the day was 300 €/MWh at 7.00-8.00 Price was high also from 15.00 to 17.00, 270 €/MWh. High prices were caused by the cold weather. Temperature was over 20 degrees Celsius below zero in the whole Finland. Minimum price of the day was 35 €/MWh and average price 94 €/MWh.

Table 6.4. *Highest and lowest NordPool area spot-prices on 5.12.2012 in Finland.[Nord Pool Spot]*

Highest spot-prices		Lowest spot-prices			
Time	EUR/MWh	Time	EUR/MWh		EUR/MWh
06 - 07	150,08	00 - 01	35,21	Min	34,77
07 - 08	300,01	01 - 02	34,92	Max	300,01
14 - 15	199,99	02 - 03	34,8	Average	94,41
15 - 16	270,04	03 - 04	34,77		
16 - 17	270,04				
17 - 18	149,99				

In the next table 6.5 there are times at which the controllable loads of the pilot customers were switch off on the 5th of December. The overall time that the loads were switched off during that day was very small. However, the times at which the loads were steered to switch off can be seen. Only customer number 2 had loads activated at 7.00-8.00 when the spot-price was at its highest. This customer was also the only customer having loads activated from 15.00-17.00, when the spot-price was the second highest. Customer number 4 had only one load activation during peak price hours and other three activations occurred during the lowest spot-prices. Customer 3 had only one load activations which happened in night-time when the spot-price was low.

Table 6.5. *Times at which the controllable loads of the pilot customers were activated on 5.12.2012.*

Customer 2	Customer 3	Customer 4
7:03-7:10	3:33-3:34	8:11-8:14
15:52-16:11		17:22-17:30
		18:30-18:33
		20:54-20:55

Approximately half of the load activations happened during the highest spot-prices and the other half during the lowest prices. From the retailer point of view, it is desirable that the loads are activated during system peak price hours. However, it is important that load control potential is known so that the power balance will not be disturbed. The effect of the steering algorithm to the electricity consumption of the following hours after load activations must also be taken into consideration. When controlling reserving loads, issues like cold load pick up must be considered as the total electricity consumption can be higher after the steering than it would have been without the steering. However, in case of the steering algorithm and direct electric heating loads, the electricity consumption of the following hours is not considerably higher than it would be without the steering. Hence, it is acceptable that the loads are activated during the cheapest hours because this will not increase the electricity consumption of the following hours in which the spot-price is higher. Shifting the electricity consumption from the cheapest spot-price hours to the hours of higher price would not be desirable from the retailer point of view. In conclusion, it can be said that based on the experiences of the pilot, there are not any major conflict situations in load control actions of the algorithm between the DSO and the retailer.

When considering the large-scale implementation of HEMS in the entire DSO's area, it must be remembered that there are quite a few challenges in equipping customers with HEMS. First, because of the technical limitations, HEMS cannot be installed to every household. Long distances between different devices and some construction materials can weaken the signals. Also the free space in the main cabinet needs to be evaluated because all meter types require different amount of free space in the main cabinet and in the DIN-rail. Secondly, finding the controllable loads that could be included to the steering algorithm was quite difficult. Most of these challenges are caused by the different types of electrical installations in houses, which make it hard to develop an efficient installation process. This increases the required time for installation planning and for the actual installations. In addition, all the pilot customers had night-time distribution tariff, so the HEMS combined with the steering algorithm is not investigated among the general distribution customers. As the great majority of the Elenia Verkko Oy's customers are general distribution customers, the large-scale potential of HEMS concept is difficult to estimate.

6.2.1 Utilizing load control in purchasing of network losses

Purchasing of network losses is an important part of the DSO's costs. DSOs need to know the amount of losses in advance in order to plan the purchasing cost effectively. The more precisely the losses and hourly fluctuation can be determined, the more cheaply the DSO can purchase its loss electricity. DSOs have traditionally used the formula for calculating the loss percentage. Because load losses are proportional to the square root of the power, accuracy of the loss percentage depends highly on how accurately the actual power is determined. (Kuisma 2007) With the transition to hourly readings from the AMR-meters, Elenia Verkko Oy has started to utilize the meter data management system in metering the network losses. Purchasing of network losses can be put out to tender only when the amount of loss energy can be determined accurately from the metering data. Elenia Verkko Oy, as a first DSO in Finland, has put out to tender the purchasing of its network losses.

When the loss energy is bought from the electricity market the price risks are tried to hedge in advance. Hedging is based on the forecast of the amount of loss energy. Some losses, like idling losses, can be forecasted well beforehand, and therefore, some of the purchases can be hedged fully in advance in the financial market. Losses related to the peak power periods, however, cannot be forecasted or hedged in advance. The loss energy must be bought from the electricity market with high price because the highest electricity prices occur typically during peak consumption hours. In these situations the DSO could utilize load control in purchasing the network losses. A lower power level during peak power hours could be achieved by switching off customers' loads and in that way reduce the amount of losses. This could result in savings to the costs of the DSO.

Customers need compensation or other incentive for giving a possibility for the DSO to control his loads. The incentive can be a one-time payment or it can be paid case-by-case basis each time the load control is used. In order for the DSO to achieve savings by using load control, the compensations paid to customers must be lower than the costs of the network losses that can be avoided by using load control. Next, it is calculated what kind of savings the DSO could achieve.

If the total electricity consumption in the Elenia Verkko Oy's area during the extreme power peak can be reduced by 10 MW the amount of network losses will reduce by 0,94 MW. (Halkilahti 2013, interview) First it was calculated how many customers should participate into the load control that the reduction of 10 MW could be achieved. Three different load control potential estimations were used; 1,3 kW, 2 kW and 2,3 kW per customer. The amount of savings were calculated by using three different electricity prices; 300 €/MWh, 500 €/MWh and 1000 €/MWh. The savings were divided by the number of customers that would have to take part of the load control in order to achieve the 0,94 MW reductions in network losses. Savings are calculated for one hour and euros are used. The results of the calculations are presented in the table 6.6.

Table 6.6. *Savings in purchasing of network losses that the DSO could achieve if the total electricity consumption is reduced by 10 MW. Savings are divided by the number of customers that would take part of the load control and determined for one hour in euros.*

Load control potential	Number of the customers needed	Price of the network losses		
		300 €/MWh	500 €/MWh	1000 €/MWh
		Savings per customer (€/customer/hour)		
1,3 kW	7692	0,04	0,06	0,12
2 kW	5000	0,06	0,09	0,19
2,3 kW	4348	0,06	0,11	0,22

As can be seen from the table 6.6 the hourly amount of savings per customer is very small. Savings vary from 4 to 22 cents per hour. In case the load control potential is 2 kW and price of the network losses 1000 €/MWh the amount of customers needed to take part of the total 10 MW load control would be 5000. The total saving for the DSO would be only 940 €, which is 19 cents per customer. Compensations paid to customers for the load control potential or investment costs of the HEMS are not taken into account in the calculations. The saving is so small that in practice it would not be possible to pay any compensation for the customers if the DSO would like to achieve savings itself. If the large-scale load control would be implemented, additional costs for the DSO would arise. As a consequence, with the present load control potential and price of the network losses utilizing load control in extreme peak power situations would not be profitable. Either electricity price or load control potential should rise significantly so that this kind of load control would be profitable.

6.3 Operation model

There are many actors involved in the demand response, each having their own roles and needs. HEMS is a service that enables the DR, and the question is how all the HEMS related operations are divided between the actors. The roles of different actors must be solved before the DR of household customers can be utilized on a large-scale. In this thesis the actors considered are the DSO, supplier, aggregator, HEMS provider and customer. There are many alternative operation models and in this chapter the DSO oriented operation model is discussed in more detail.

Operations that are related to HEMS service are marketing of the new service, installations, customer service, maintenance, technical support, billing and load steering. DSOs and suppliers already have some of these resources and relationship to a large customer group. Therefore, it would be beneficial for the HEMS provider to co-operate with the DSOs or suppliers. Besides the operations related directly to the HEMS service, different actors' needs for the DR must be considered. It is important to combine the needs in a way that all parties can benefit from the DR. This can be achieved if none of the parties will alone determine the terms of the DR, but they are made by consensus.

In DSO oriented operation model the HEMS provider would co-operate with the DSO firmly but it would be the DSO who invests the HEMS for the customer. This is needed because in order to accomplish any effects, a large number of customers must be equipped with HEMS in a certain area. It can be assumed that this would not be possible in the near future without the DSO investing the equipment. The investment costs of the HEMS could also be divided between the DSO and the customer, because HEMS would benefit both. DSO would benefit from load control and smaller power level and the customer could also achieve lower power level and savings in electricity consumption and also utilize the real-time consumption monitoring. The DSO would pay for the possibility to control the loads for the customers.

The incentive for the DSO to invest the HEMS-solution would be to limit the peak power level together with the network tariff structure and utilize the load control. These actions could result in savings for the DSO. According to the earlier calculations some savings could be achieved, but the savings are quite small. One incentive for the DSO could also be the control of the distribution network's distribution capacity during fault conditions. In addition, the DSO and customers could benefit from the additional services around HEMS.

In this operation model the HEMS provider would arrange customer service, billing and installations in co-operation with the DSO. This would benefit the HEMS provider greatly and allow them to concentrate on the core business, like delivering the HEMS equipment and maintaining the HEMS database. DSO would pay for the access to the HEMS database. Technical support and maintenance should also be organized in co-operation with the DSO and HEMS provider. It can be assumed that technical support would be in a significant role at least in the beginning of the large-scale HEMS roll out. Issues that concern DR and load control would be handled by the DSO and customer would contact the DSO with these issues. Also power band related issues would be handled with the DSO.

Controlling of metering data and customer information system makes the role of the DSO very essential in DR. However, DSOs are highly regulated and the Electricity Market Act states that the electricity distribution operations must be separated from other business. Because of this, DSOs cannot utilize load controlling commercially in the electricity markets within the current regulation. These extra services offered by the DSOs could be harmful to the neutrality and indiscrimination aspect. In Finland and Sweden the regulators' opinion is that extra devices and services should be offered by some third party. There is a risk involved in these services that if only some of the customers use them, the costs of the development and using will be added to the tariffs for all customers to pay. (Oksanen 2011) In addition, it can be questioned whether different extra services include into the core business of the DSOs. On the other hand, it must be remembered that DSOs would not probably have the incentive to equip the customers with HEMS if they cannot earn money for it.

In addition, one challenge in the DSO oriented operation model is how the different actors' needs for DR can be taken into account. As mentioned earlier, demand that is optimized based on either generation or distribution only may be non-optimal to the other party. Load control actions that are executed by the DSO can cause problems for the retailer as can disturb the retailer's power balance between the electricity procurements/production and the consumption/sales.

One possible way to implement the DR without causing problems to any parties could be the introduction of power band network tariff and use of load control within the power band. That way both supplier and DSO could benefit. In this model the DSO would determine the power band together with the customer, and supplier would be responsible for the load control. Supplier would carry out the load control actions and consider the limitations caused by the power band. Customers would be able to change the threshold value and it would be separate from the power band limit. Considering the power band would probably reduce the effects of the load controlling, but still benefits could be achieved. In this model either DSO or supplier would be responsible for the HEMS equipment. Supplier would pay compensations for the load control actions. Network distribution fee would be collected through the power band by the DSO and HEMS provider would be responsible of the technical support and maintenance. Consequently, customer would have to contact all parties; supplier, HEMS provider and DSO, which can be very confusing to the customer and not user-friendly. This is one of the downsides of this model.

It must be remembered that if the customer is not willing to equip his household with HEMS or participate the load steering, none of the operation models will be possible. This sets the customer informing about the DR and load controlling into a significant role. In addition, it can be questioned whether it is needed that the DSO or supplier is acting as an aggregator in load controlling. With the help of HEMS the customer could optimize the electricity consumption according to the market price and also utilize tools, like the steering algorithm, to limit the peak power. That way the energy usage would be optimized according to both supplier and DSO, and any additional load control actions would not be needed.

7 CONCLUSION

In this work, a small-scale pilot study of HEMS was carried out with the cooperation of a service provider company There Corporation. A new steering algorithm was developed to support the power based power band network tariff. The purpose of the steering algorithm was to help the customers to reduce the power level and especially the power peaks. The pilot study showed that the steering algorithm is working properly and the peak powers can be decreased with the help of the algorithm. Based on the experiences of the pilot and customer feedback the algorithm can be further developed. Pilot study also enabled to recognize some issues that should be considered when designing future network tariffs and HEMS services. These were discussed in chapter 6.1.

In the future, there will be some significant changes in the electricity market that will affect to the future tariff structure. Changes in the operational environment, such as small-scale electricity production, drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level for the DSO. The power band concept is considered to be one of the best options for the future network tariff and it was introduced in chapter 4. Also changes in the electricity production create the need for new functionalities around demand response and load control. Distributed generation and renewable energy sources are issues that drive the DSOs and TSO to develop new demand response opportunities.

HEMS is a service that enables the demand response and load control actions. The steering algorithm is based on the controllable loads that can be steered to switch off when the total power consumption of the household increases. Controllable loads were tried to find from the households and include to the steering algorithm. However, finding these controllable loads was quite difficult. Customers with direct electric heating had quite positive attitude towards the controlling of heating loads, but there were still some technical challenges. The preferred method to steer the heating loads was to steer the temperature drop functionality of the thermostat. Quite a few thermostats have temperature drop functionality, especially the newer ones, which can be steered with the HEMS. However, the more automation the heating system contains the more difficult it is to steer with external equipment. Many heating systems include steering opportunities themselves, which cannot be steered with HEMS. All the controllable loads that were used in the pilot were direct electric heating loads. The overall user experience of the steering algorithm was quite positive. Customers that had controllable loads in the steering algorithm said that the load control actions of the steering algorithm could not be noticed for the most of the time and the comfort of living was not suffering.

DSO could benefit from the large-scale use of HEMS-solution that enable demand response and smaller power level. The average load control potential of the pilot customers varied from 0 to 1,7 kW. The largest decrease in hourly peak power was 1,2 kW. An important incentive for the DSO to try to limit the power level is the positive effects on the distribution network dimensioning. If the load control actions of the steering algorithm are implemented on a large-scale the effects can be utilized in network design. It was investigated that in a certain feeder where the power situation was quite strict, the peak power could be reduced by 7,8 % if less than half of the customers in that area would be equipped with HEMS and load control would be used during the peak power hours. This would bring savings for the DSO as the network renovation could be postponed. This result looks encouraging but more research about this topic is needed.

It was investigated if there are any conflict situations in load control actions of the algorithm between the DSO and retailer when the spot price is high or low. Demand that is optimized based on either generation or distribution only may be non-optimal to the other party. It could be said that based on the experiences of the pilot, there were not any conflict situations in load control actions of the algorithm between the DSO and the retailer. After that an analysis was made on how the load control could benefit the DSO in purchasing of network losses. Network losses related to the peak power periods cannot be forecasted or hedged in advance. The loss energy must be bought from the electricity market with high price because the highest electricity prices occur typically during peak consumption hours. In these situations the DSO could utilize load control in purchasing the network losses. A lower power level during peak power hours could be achieved by switching off customers' loads and in that way reduce the amount of losses. This could result in savings to the costs of the DSO. The hourly amount of savings per customer was calculated in chapter 6.2.1. The savings were very small, only from 4 to 22 cents per hour per customer. As a consequence, with the present load control potential and price of the network losses utilizing load control in extreme peak power situations would not be profitable if taking into account the investment costs and compensation paid to customers.

The price range of the power band was calculated in chapter 6.1.2. The calculated €/kW price was determined in a way that the yearly distribution fee would be the same as the present distribution fee. The calculated €/kW band price was for one month and the prices varied from 4,2 to 11,7 €/kW depending on the maximum power of the pilot customer. However, the price cannot be calculated based on individual customers but it must be determined in the entire distribution network level. Average distribution fees would not change and also the proportion of the distribution from the electricity price would remain the same. The calculated values show that the variation is great and if power band would be introduced there would probably be significant changes in the customers' distribution fee. Therefore, it is very important that customers are informed properly and they feel that they have real opportunities to affect to the band size and consequently, to the distribution fee.

The purpose of the pilot study was not only to investigate the steering algorithm, but also the entire power band tariff concept. In chapter 6.1.1 the power band concept was analyzed. Two essential observations were made of the band determination and excess usage events. First, in order to avoid the lack of incentive to control the power level during summertime, separate bands for summer- and wintertime are needed. Secondly, it is important that the band is allowed to exceed for some reasonable times. The best way to determine the band size would be to determine first the band size according to the maximum power of the last summer or winter season and then investigate if the smaller sizes are possible within the allowed excess usage events.

There are many actors involved in the demand response, each having their own roles and needs. The roles of different actors must be solved before the DR of household customers can be utilized on a large-scale. One possible way to implement the DR without causing problems to any parties could be the introduction of power band network tariff and use of load control within the power band. In this model both supplier and DSO could benefit from the DR. DSO would determine the power band together with the customer, and supplier would be responsible for the load control.

Briefly, the use of the power band steering algorithm was piloted successfully. It was seen that the peak powers were reduced as well as the overall power level of those customers that had controllable heating loads in the steering algorithm. However, the steering of the controllable loads enabled relatively small savings for the DSO compared to the investment costs and some of the monetary savings could be achieved only locally. One way to achieve better steering possibilities is to consider HEMS during the construction of new buildings. Although it is completely possible to install HEMS with load control functionalities for the most of the existing households, there are some challenges in finding the controllable loads that can be steered with HEMS. The power band tariff must be investigated further before it can be introduced to customers. Also the operation model of the demand response must be developed in cooperation of all parties, meaning DSO, supplier and HEMS provider.

Further study

The purpose of the pilot study was not only to investigate the steering algorithm, but also the entire power band network tariff concept. However, the power based network tariff was not provided to the customers. That would have given real incentives to decrease the power level and fully utilize the possibilities of HEMS. For example, the meaning of the alarm messages would probably have been greater. Hence, further study about the power band concept is needed.

In addition, all pilot customers had night-time distribution tariff throughout the pilot which set some limits to the analysis, as the reserving heating loads could not be used outside the night-time hours. In some cases it would have been beneficial if some of the reserving loads could have been used also outside the 22:00-07:00 night-time hours. During the pilot study an idea came out that there could be a possibility to steer the loads to switch on when the power level is low. For example, some reserving heating loads could be used during the daytime when customers are not home and the power level is low. This could have decreased the night-time power level. The steering algorithm could be further developed in other ways too.

The operation model of the demand response related issues must be developed in cooperation of all parties before any services can be implemented on a large-scale. To achieve benefits in real electricity market environment the HEMS-units would need to be developed to control a large number of collectively. This requires active co-operation and piloting with suppliers, DSOs, service providers and consumers.

The effects of the large-scale implementation of HEMS in the entire DSO's area must be further investigated. In order to further investigate how small band sizes customers could achieve, more information about the steering algorithm's effect on the power level throughout the year is needed.

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