LAPPEENRANTA UNIVERSITY OF TECHNOLOGY
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Degree Program in Electrical Engineering

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UTILIZATION OF AMI-TECHNOLOGY IN A MULTILAYERED DEMAND RESPONSE SERVICE ENVIRONMENT

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TIIVISTELMÄ

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AMI-teknologian hyödyntäminen monitasoisessa kysyntäjousto ympäristössä

Diplomityö
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116 sivua, 21 kuvaa, 18 taulukkoa ja 2 liitettä

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Hakusanat: AMI, AMR, Kysyntäjousto, sähkömarkkinat

Työssä tutkittiin edistyneiden mittausjärjestelmien toimintaa vaativassa kysyntäjoustoympäristössä. Työn tarkoituksena oli selvittää millaisia haasteita sekä pullonkauloja AMI-järjestelmien käytössä saatettaisiin kohdata, kun järjestelmiä käytettäisiin haastaviin kysyntäjoustotehtäviin.

Haasteiden sekä pullonkaulojen selvittämiseksi luotiin monitasoinen kysyntäjoustopalvelu konsepti, joka toimii seitsemällä erilaisella markkinatasolla. Nämä markkinatasot koostuvat Pohjoismaisista sähkömarkkinoista sekä kansallisista reservimarkkinoista Suomessa. Palvelun markkinatasot toimivat kiintopisteinä joita vasten AMI-järjestelmän suorituskykyä mitattiin.

Työssä selvisi, että nykyiset AMI-järjestelmät pystyvät parhaimmillaan toimittamaan kysyntäjoustoa haastavimmillekin markkinatasoille vasteaikojen näkökulmasta tarkasteluna. Lisäksi työssä selvisi, että laajamittaista kysyntäjouston käyttöönottoa hidastavat kolme merkittävämpää haastetta. Merkittävimmät haasteet kysyntäjouston käyttöönotolle olivat heikko standardisointi järjestelmien osalta, mahdolliset ongelmat tietoliikenneyhteyksissä sekä nykyinen sähkömarkkinaregulaatiomalli.

ABSTRACT

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Utilization of AMI-technology in a Multilayered Demand Response Service environment

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Keywords: AMI, AMR, Demand Response, Electricity Markets

This thesis studied the performance of Advanced metering infrastructure systems in a challenging Demand Response environment. The aim was to find out what kind of challenges and bottlenecks could be met when utilizing AMI-systems in challenging Demand Response tasks.

To find out the challenges and bottlenecks, a multilayered demand response service concept was formed. The service consists of seven different market layers which consist of Nordic electricity market and the reserve markets of Fingrid. In the simulations the AMI-systems were benchmarked against these seven market layers.

It was found out, that the current generation AMI-systems were capable of delivering Demand Response on the most challenging market layers, when observed from time critical viewpoint. Additionally, it was found out, that to enable wide scale Demand Response there are three major challenges to be acknowledged. The challenges hindering the utilization of wide scale Demand Response were related to poor standardization of the systems in use, possible problems in data connectivity solutions and the current electricity market regulation model.

FOREWORD

Cluttered house means a cluttered head – Some words muttered by an Old Russian lady while cleaning my friend's house. Motherly advice, which probably went unnoticed knowing my friend. However, there may be some wisdom in the murmurs of an old lady.

Indeed, clutter in house may signify clutter in head, but why does house get cluttered? Reasons might be many, but I'd like to think that we are busy, busy doing something interesting, something we love. I have been busy all my life based on the cleanliness of my house, but I have been busy especially lately, as I have found something that truly is interesting and I'm feeling passionate about.

My studies in Lappeenranta introduced me to the world of electricity markets and for this I'd like to thank Satu Viljainen and Jarmo Partanen for all the high-quality education and teaching they have poured into me. I'd also like to thank Empower IM for providing me this opportunity to write this thesis, and all the great coworkers here in Helsinki and Hämeenlinna, especially Jan Segerstam and Joni Aalto, who have helped and guided me throughout this thesis.

I would also like to thank my parents Tarja and Markku and my little brother Janne, for supporting and encouraging me during my studies in Lappeenranta. I'd like to also thank my fellow students in Lappeenranta for all the great times we had. And lastly I'd like to thank my dearest Aino, who has been supporting and helping me in the making of this thesis, and in my everyday life.

Usually at this point people tend to state that it is time to move towards new challenges and they sort of clean their house from clutter, but I think I'm not cleaning my house, not yet. I'm busy.

Helsinki, October 2014

Olli Huotari

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ABBREVIATIONS AND SYMBOLS

AMI	Advanced Metering Infrastructure
BRP	Balance Responsible Party
CEN	European Committee of Standardization
CENELEC	European Committee for Electrotechnical Standardization
CET	Central European Time
CIS	Customer Information System
DR	Demand Response
DSL	Demand Side Load
DSO	Distribution System Operator
EC	European Commission
EDM	Energy Data Management
EMS	Energy Management System
ETSI	European Telecommunications Standards Institute
EU	European Union
FCR	Frequency Containment Reserve
FRR	Frequency Restoration Reserve
GPRS	General Packet Radio System
GSM	Global System for Mobile Communications
GWEC	Global Wind Energy Council
HEMS	Home Energy Management System
IEA	International Energy Association
IEEE	Institute of Electrical and Electronics Engineers
IHD	In-Home-Display
ITEA	Information Technology for European Advancement
NIST	National Institute of Standards and Technology
OECD	Organization for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OTC	Over-the-Counter
PLC	Power Line Communication
PV	Photovoltaic

RES	Renewable Energy Source
RTO	Regional Transmission Organization
SEAS	Smart Energy Aware Systems
TSO	Transmission System Operator

Hz	hertz
W	watt
Wh	watt-hour

1 INTRODUCTION

In 2006 the European Commission published a Green Paper titled as "A European Strategy for sustainable, Competitive and Secure Energy" which declared that the Europe had entered a new energy era (European Commission, 2006). It could be claimed that this Green Paper gave the official push towards Smart Grids research in the Europe.

The push toward Smart Grids got more weight behind itself as the leaders of the European Union decided a year later to support the 2020 climate and energy package. The 2020 climate and energy package promotes targets of reducing greenhouse gasses by 20%, raising the share of renewables in energy production by 20%, an improving the EU's energy efficiency by 20%. (European Commission, 2012)

In the wake of the EC's push towards energy efficiency and Smart Grids, Finland started a massive roll-out of smart meters in 2009 with aim to have at least 80 % of the consumption sites equipped with a smart meter by the end of 2013. In 2014 the smart meter roll-out has been finished and the coverage of smart meters is closing on near 100 %. (SmartRegions, 2014)

Now, the dust has settled and remote meter reading services have been enabled and running successfully throughout the country. However, the companies have now started to ponder, what else could be done with the smart metering infrastructure? This thesis studies the possibilities of using the smart metering infrastructure in demand response activities and analyses the performance of the current generation systems by pairing it with a state-of-the-art demand response service.

1.1 Objectives and scope of the study

Objectives of the study are to identify and define the most common bottlenecks restraining the usage of AMI-technology in Demand Response related activities. This is done by studying a use case which was defined in an ITEA (Information Technology for European Advancement) 2 project: Smart Energy Aware Systems

(SEAS). The use case envisions a multilayered demand response service which is intended to be used as an imbalance management tool for the electricity retailers. The research objectives are listed in table 1.1 and explained below.

Table 1.1 Research objectives

Research objectives
1. Define the bottlenecks and limitations for pairing AMI-technology with a state-of-the-art Demand Response service 2. Try to find possible solutions to resolve the problems caused by the limitations and bottlenecks 3. Evaluate the suggested solutions against the current market environment.

The first objective of the study is to find and define the bottlenecks and limitations of the Advanced Metering Infrastructure-technology when paired with the multi-layered demand response service. This is done by comparing the requirements of the multilayered demand response service and the abilities of the AMI-technology through literature review and interviews.

The second objective of the study is to suggest possible solutions to resolve the problems caused by the limitations and the bottlenecks. The objective is to find the best possible solutions to enable demand response by using available AMI-technology.

The suggested solutions are then evaluated in the current electricity market environment from the viewpoints of different market actors, such as distribution system operators or electricity retailers. This is the third objective of the study.

To summarize, the objectives are to see how well the current AMI-system is able to perform in a state-of-the-art Smart Grid environment.

1.2 Structure of the study

This study is divided into three major parts. First part of the study consists of the electricity market and Smart Grid theory related to the Multilayer Demand Response Service. The theory part of this study is extended over the chapters 2 to 3.3. Objective of this part is to define the current requirements and limitations of current operating environment and to give reader a basic knowledge related to Smart Grids and Demand Response.

The second part of the study constructs the Multilayered Demand Response Service and studies the ability of the current AMI-technology to perform in a state-of-the-art market environment. This part of the thesis is presented in chapter 4. Objective of this part is to highlight the most crucial bottlenecks and limitations of the AMI-technology in the new market environment.

In the third part of the study the results gained from the second part of the study are analysed and solutions are suggested to the recognized problems. This part of the study also takes a stand on the problems arising from the market environment and near-future changes to the operating environment. The analysis is presented in chapters 5 while conclusions are drawn in chapter 6. This part ends the study with the conclusions drawn from the second and third part of the study.

2 ELECTRIC POWER MARKETS

The electricity power market can be described as an intricate system of many subsystems. It consists of electricity production, electric power transmission, electric power distribution and electricity trade. What makes this system so complex, is that each of the systems are interconnected and there has to prevail a perfect balance within the system at all times. The electricity generation has to match electricity consumption at all times, otherwise the system experiences power failures such as blackouts, the electrical power transmission and power distribution has to be up to the task of transferring and distributing tremendous amounts of electrical power and the electricity market has to function correctly to be able to send correct price signals to different market parties. All in all, the electricity power market can be summarized by the following quote from the Handbook of Networks in Power Systems by A. Sorokin & al.:

> *Apart from its economic features such as the no-direct-storability, lack of good substitutes and inelastic demand, the technical peculiarities of the electricity as a commodity makes the electricity market a very specific one. – (Bompard & Ma, 2012)*

As the quote states, the electricity power market is quite specific one and also quite vast. Nevertheless, this study concentrates more on the economic part of the electricity power market, commonly known as electricity trade.

2.1 Brief history of the Finnish electricity market

Before the year 1995 the electricity market in Finland was heavily regulated. The electricity retailers were local distribution system operators and they were in a position where they had a monopoly over the local electricity retail market in their respective networks. The electricity retailers typically procured electricity by signing long contracts with the electricity producers through Over-The-Counter-trades or alternatively they had electricity generation of their own. This changed in 1995 when the new Finnish electricity market act was enacted. It was the start of electricity market reform in Finland and meant that electricity wholesale and retail markets were now deregulated. This meant that the distribution and production of electricity had to be uncoupled and this opened new opportunities for the electricity end users. For example, instead of being forced to buy their electricity from the local DSO, the end users now had the freedom to choose where to buy their electricity. (Partanen, et al., 2014)

Another change, the electricity market reform introduced, was the way how electricity was procured by the electricity retailers. The new market environment meant that there was a new way to procure electricity, in addition to the OTC-trades, through the electricity exchange. In 1998 Finland joined the Nordic power exchange, the Nord Pool Spot, instead of building its own national power exchange. This meant that Finland was now part of the common Nordic electricity exchange with Norway, Sweden and Denmark. (Partanen, et al., 2014; Nord Pool Spot AS, 2014)

The market model of the Nord Pool spot is, as the name suggests, a power pool with an option for OTC-trade. The Nord Pool spot uses a market mechanism called *market splitting*. Basically, what this means is that the market calculates for the whole system a unified price called *system price* and if the system is experiencing transmission congestions the market calculates a new price for the congested areas called *area price*. The pricing mechanism is illustrated in practice in Figure 2.1 (Nord Pool Spot AS, 2014; Partanen, et al., 2014)

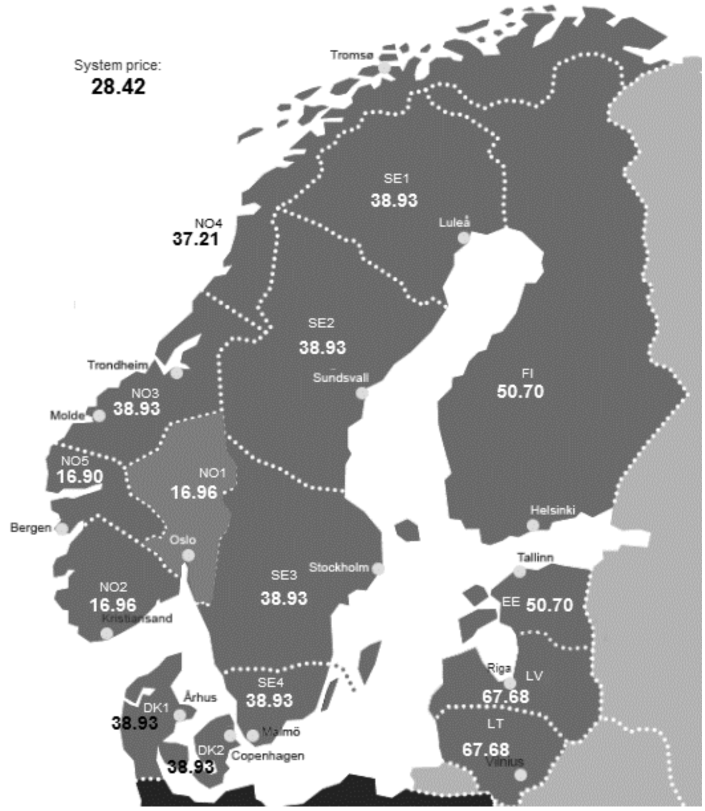

Figure 2.1 Pricing mechanism in action: on 2nd of May 2014, the system has calculated a system price and several area prices (Nord Pool Spot AS, 2014)

The electricity market acts as a trading place between different actors, while the electricity exchange and OTC-trade are the tools used for trading. The electricity market actors can be divided into two groups. The first group consists of electricity producers, such as nuclear power plants or hydro power, and they operate in the section of electricity market called the wholesale market. The second group consists of electricity retailers who buy electricity from the wholesale market and resell it to the end users. This section of the market is called the retail market. The connections between the electricity market actors can be seen in Figure 2.2 (Partanen, et al., 2014)

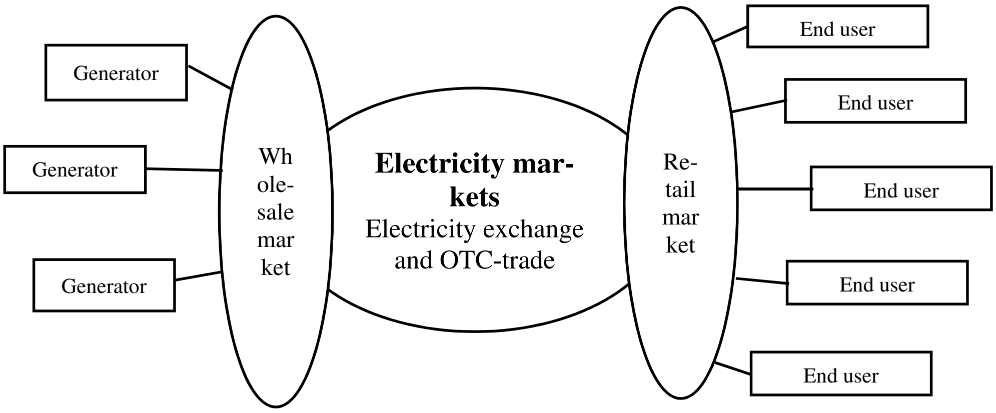

Figure 2.2 Shows the structure of the electricity market. The market is divided into wholesale and retail markets, connected by the electricity exchange and Over-The-Counter trade. (Partanen, et al., 2014)

As can be seen from the figure 2.2, the electricity market consists of wholesale market and the retail market. What is not clear from the figure 2.2 is that the electricity market consists also from ancillary markets operated by the national transmission organization Fingrid. The wholesale market is a market place where physical electricity trade takes place between market participants, such as generators and retailers. In case of Nord Pool Spot, this means that the physical trade takes place via such market mechanisms as Elspot, Elbas and OTC-trade. In 2013 84% of the physical electricity trade took place in the Elspot and Elbas. The remaining 16% was traded via the OTC-trade, regulation market, and reserve markets.

Whereas the wholesale market could be described as the supply of electricity, the retail market is a bit more complex entity. The electricity retail market in the Nordic countries is the operating field of electricity retail companies. Electricity retail market connects the end users and electricity supply together, and it could be said that electricity retail companies operate at the both ends of the electricity market, acting as a link between the supply and consumption. The electricity retailer's daily operations consist of buying and selling electricity at the wholesale market level and then reselling the electricity to the end users at the retail market level. Simply put, the electricity retail companies resell electricity to end users and gain compensation from the differences between the wholesale market price and the retail market price. (Partanen & al., 2014)

In the future, the electricity retail market is going to undergo a major reform partly because of the EU 2020 targets. Finnish energy industry representative, Finnish energy industries (Energiateollisuus) has suggested in its electricity retail market vision 2020 (Vähittäismarkkinavisio 2020) that the electricity retail market is going to undergo significant changes by the year 2020 (Energiateollisuus, 2013). The most apparent change by 2020 will be a move to a retail centric model in the electricity market. NordREG, an organization for the Nordic energy regulators also endorse this model and describe it as follows:

> *"A retail centric model: this model, which NordREG recommends, is characterized by the defined customer interface, where a majority of the customer contacts will be handled by the retailer. However, the Distribution System Operator (DSO) will still have ultimate responsibility towards customers regarding strictly network related issues." – NordREG, 2013*

The retailer centric model will have a strong effect on the future development of the Nordic electricity market. The model is being adopted all around the Nordic countries apart from Iceland, which is not part of the common Nordic electricity market. Other significant changes the Finnish energy industries lists in its vision for 2020 are as follows:

- Introduction of new energy efficiency services, such as demand flexibility and in-home-display (IHD) technology
- Transition from consumers to prosumers, meaning small end-users whom have electricity production in addition to electricity consumption
- Increase in usage of electric vehicles

Even though the above mentioned changes are not strictly connected to the electricity retail market, their effect on the development of the electricity retail market will be significant. The new Smart Grid enabling technologies in combination with the electricity retailer centric model will be increasing the role of the end-customer in the electricity market environment. Nowadays the end-customers can be seen as static loads, whereas in the future there is a possibility where the end-customer is an active enabler or producer of different electricity market related smart services, such as demand response. The briefly touched Smart Grid aspect will be discussed in greater detail in chapter 3. (Energiateollisuus, 2013)

The third part of the Nordic electricity market is the ancillary part of the market. The ancillary electricity market domain is meant for operational upkeep of the electrical power system. If the ancillary market domain were to be built into the figure 2.2, the market domain would be near the wholesale market domain. The ancillary market domain consists of such tools as the regulating power market and the multiple power reserves operated by the Finnish national transmission system operator Fingrid. (Fingrid, 2014)

The ancillary market domain is fairly minor when measured in market volume and compared to the wholesale electricity market domain. For example, in May 2014, the biggest daily volume for Finland was 4000 MW worth of physical power at regulating market, when at the same time in Elspot the biggest daily buy volume was 130 000 MW worth of physical power. (Nord Pool Spot, 2014)

In the next chapters the difference between Nord Pool Spot operated markets and Fingrid operated markets is explained. The following chapters also introduce all the market layers available in the Nordic electricity market, excluding the financial markets operated by the Nasdaq OMX Commodities.

2.1 Nord Pool Spot operated markets

The Nord Pool Spot operated markets consist of two markets, Elspot and Elbas. The markets extend over all the Nordic countries providing a common market place for all the producers and electricity retailers in the Nordic countries. In the following sub-chapters a more detailed review of the Elspot and Elbas is given to define the specific market functionalities.

2.1.1 Day-ahead market Elspot

Elspot is a day-ahead market operated by Nord Pool Spot. Elspot operates on a principle of closed auction where different market participants can make offers of their generation for the market and make bids based on their consumption. The underlying product in the Elspot is electricity power contract which always lead to a delivery of physical electricity. (Lucia & Schwartz, 2002; Valtonen, et al., 2012)

The contract size in Elspot is 0,1MW and multiples of it. In addition to the varying sizes, the contract durations may also vary. The most typical duration for a contract would be of a one hour, but there are also special contracts, called block contracts, available. Block contracts are formed from individual hourly contracts and can be of any length, as long as the minimum length is 3 hours. (Valtonen, Partanen, & Honkapuro, 2012)

The price of the electricity contract is formed by using the above mentioned closed auctioning method. In closed auctioning method the Elspot market participants make buy and sell offers once a day to the Elspot market. The market participants do not know each other's market positions in order to limit the market participants from using market power. The Elspot then calculates a single price, called system price, for the whole market from the offers made by the market participants by using marginal pricing principle. (Partanen, et al., 2014)

Marginal pricing principle is a method where the market aggregates all the offers of supply and bids of demand into supply and demand curves. Then the market calculates the market price from the cross section of these curves for each hour of the next day. The now formed system price represents the most expensive generation method needed to balance the electricity consumption or from other perspective, the price that the market participants are willing to pay for electricity. The market price formation from supply and demand curves is illustrated below in Figure 2.3. (Partanen, et al., 2014; Valtonen, et al., 2012)

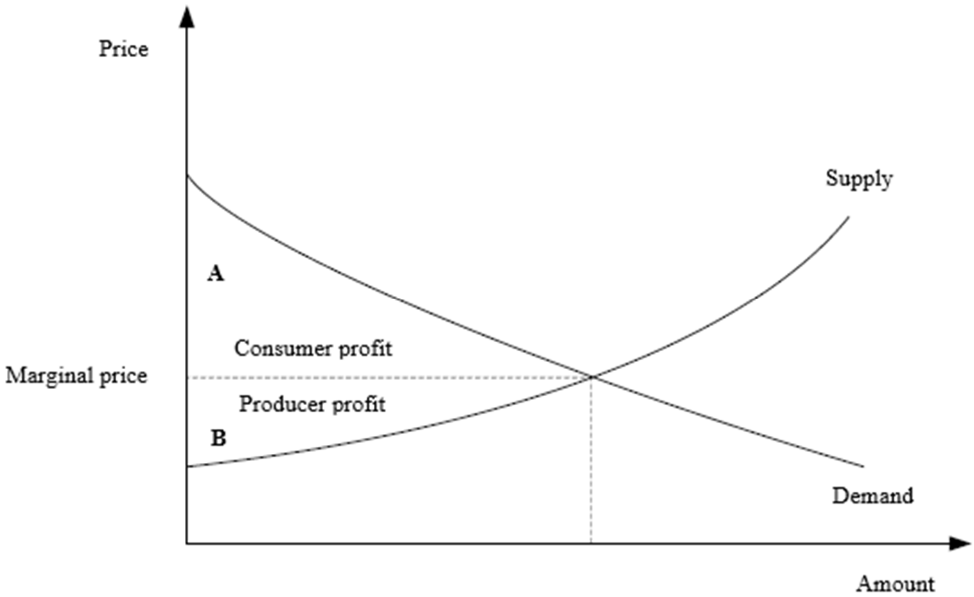

Figure 2.3 Supply and demand curves used for spot price formation (Viljainen, 2013)

The system price is typically formed after the gate closing time 12:00 Central European Time (CET) at day before the delivery hour. Once the system price has been formed the trades are settled between the market participants for the following day. From 00:00 CET next day the power contracts are physically delivered hourly according the trade settlements. (Nord Pool Spot AS, 2014)

The system price defines the price of the electricity for all market areas of Nord Pool Spot, however, the system price does not take into account any transmission capacity restrictions. If there are no congestions or bottlenecks in the transmission grid the system price would be the same on all the markets, but when such bottlenecks occur the market divides into separate price areas. (Partanen, et al., 2014)

These price areas represent the local conditions in the transmission network and often suggest that there is a deficit of transmission capacity. If the area price is higher than the neighboring areas, the area is experiencing underproduction and is not being supplied by the neighboring price areas. On the other hand, if the price area is lower than the neighboring price areas the area is usually experiencing over production of electricity and is not able to transfer the surplus electricity to the other price areas. (Partanen, et al., 2014)

Next chapter takes a look at the Elbas market which is a supplemental market for the Elspot market. While most of the electricity trade happens on the Elspot market, the Elbas market acts as an intraday balancing market, where the electricity suppliers and retailers can balance their open position at the market.

2.1.2 Intraday market Elbas

Elbas name comes from the acronym Electricity Balance Adjusting System and is the brainchild of Finnish and Swedish transmission system operators (TSOs) Fingrid and Svenska Kraftnät. The idea of Elbas was born in 1997 and later on the Elbas was introduced to the public in 1999 in Finland and Sweden. The TSOs created Elbas to meet the need for a market mechanism which allows adjusting electricity imbalance after a round of Elspot trading. Simply put, Elbas was created as an aftermarket for the Elspot. (Nord Pool Spot AS, 2010)

Wherein Elspot is the day-ahead market where trading takes place once a day for every day of the year, Elbas is the intraday market where trading takes place 24 hours a day, every day. Elbas also differs somewhat on the market coverage compared to Elspot. While Elspot covers the Nordic and Baltic countries, Elbas extends to Germany as well. (Nord Pool Spot AS, 2014)

As mentioned earlier, Elbas was created for balancing supply and demand, which means adjusting actual generation and consumption between the suppliers and generators. Elbas allows market participants to make intraday trades up to one hour before the actual delivery hour. This gives market participants the opportunity to manage their power balance in near real-time. The timeframe for intraday trading is illustrated in Figure 2.4 (Faria & Fleten, 2011; Nord Pool Spot AS, 2014; Partanen, et al., 2014)

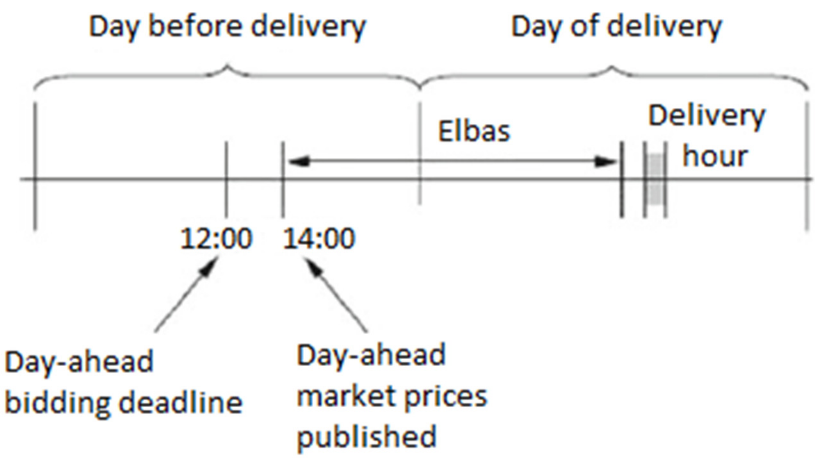

Figure 2.4 Illustration of the trading timeframe used on Elbas market mechanism, adapted from (Faria & Fleten, 2011)

Making bids to the Elbas differs to some degree from the Elspot. Like in the Elspot, the minimum contract size of 0,1Mwh and the usage of block offers in bidding are same. In Elspot the gate time for bids is 12 hours before the delivery hour, but in Elbas the gate time for bids is one hour before the delivery hour. The market price formation also differs greatly from the Elspot. Wherein Elspot the market price is formed by using marginal pricing principle, in Elbas the market price is formed by using first-come, first-served principle. (Nord Pool Spot AS, 2012)

The Elbas market with the Elspot market are the main markets in the wholesale market section. These two markets are also supplemented by the bilateral OTC-trade, but the OTC-trade is left outside the discussion this time as it does not fall under the scope of the study. To recap the main points of the markets associated with the whole sale market the main points of each market are listed in Table 2.1 below.

Table 2.1 Nord Pool Spot's main markets Elspot and Elbas clarified

Nord Pool Spot's markets	
Elspot	**Elbas**
Elspot is a day-ahead market which is used for daily electricity procurements. The market price is determined by using marginal pricing principle. The electricity procurement bids have to be submitted daily before the gate closure time 12.00 CET. Minimum bids size is 0,1MW and successful bids always leads to a delivery of physical electricity.	Elbas is an intraday market which is used to correct imbalances in daily electricity procurement. The market price is determined by first come, first served principle. Bids have to be submitted 1hour prior the delivery hour. Minimum bid size is 0,1MW and successful bidding always leads to a delivery of physical electricity.

This concludes the part consisting of Nord Pool Spot related markets. In the next chapter the Fingrid operate markets are presented and described.

2.2 Fingrid operated markets

Fingrid operates the ancillary market services in Finland. The market services consist of the regulating power market and the power reserves used for frequency management in the national transmission electricity grid. The following sub-chapters concentrate on describing the market mechanisms related to the above mentioned market services.

2.2.1 Regulating power market

Regulating power market in Finland is part of the Nordic regulating power market and is maintained by the Finnish transmission system operator Fingrid. The reason why Fingrid operates the regulating power market is because it does not own enough regulating power capacity of its own.

In order for the market participant to participate to the regulating power market the market participants have to have a regulating market agreement with Fingrid, or they have to become a balance responsible party (BRP). Market participants whom cannot enter into a regulating market agreement with Fingrid have to participate via their own BRP. Possible reasons for not being able to enter into an agreement with Fingrid might be insufficient amount of regulating power capacity or otherwise inadmissible regulating power capacity. Fingrid has set few limitations for the participating regulating power capacity. In order to be able to participate the regulating power capacity has to be capable of real-time verification. The minimum size for participating regulating power capacity is 10MW and the reserve has to be able to deliver all 10 MW in 15 minutes. (Fingrid, 2014)

The price formation on the regulating market is carried out by Fingrid. The price is formed by using a method where every usage hour gets a down-regulating and an up-regulating price. These prices come from the up- and down-regulations carried out by the Fingrid. The principle used in pricing the up- and down-regulations is as follows:

When it is up-regulating hour the bids are arranged in a way that the most affordable bid is used first. The final price for the up-regulating hour will be the most expensive bid received. However, the minimum price for the up-regulating hour will be Nord Pool Spot's Finland's area price (Elspot FIN). Respectively when it is down-regulating hour, the most expensive bid is used first and the final price will be the most affordable bid used. The price of down-regulating will have a maximum value of Nord Pool Spot's Finland's area price (Elspot FIN). (Partanen, et al., 2014)

Fingrid carries out the up- and down-regulations in the price order described above and pays to the regulating power resources. The up- and down-regulating bids have to be submitted 45 minutes before the regulating hour. Below Figure 2.5 presents the actual up- and down-regulations carried-out by Fingrid from June 2014. (Fingrid, 2014)

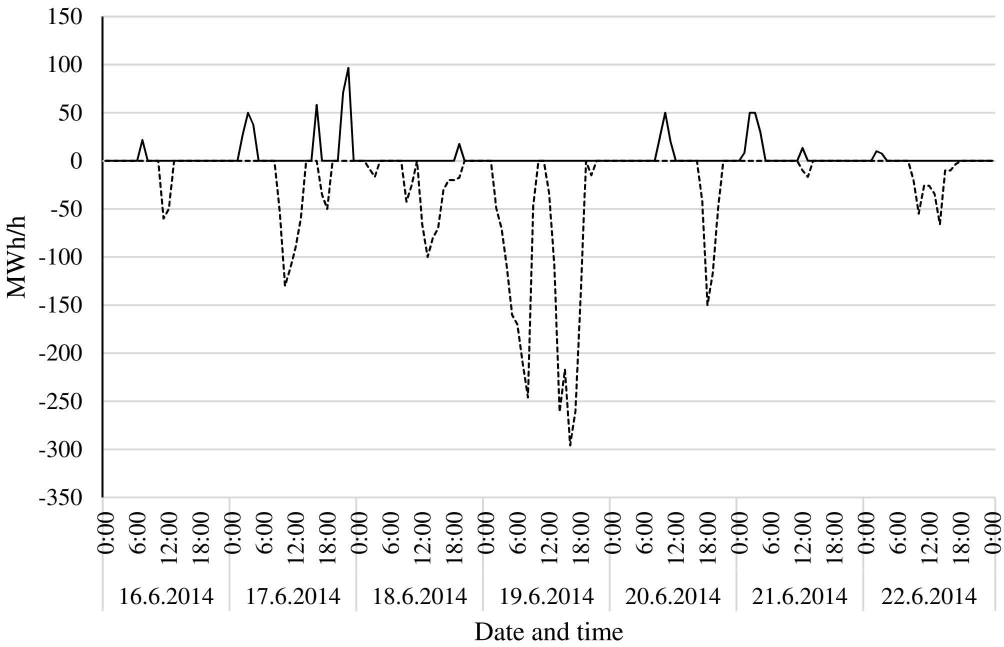

Figure 2.5 Actual up- and down-regulations from June 2014 (Fingrid, 2014)

In addition to the regulating market the ancillary market can be seen consisting of Fingrid's power reserves. In the next chapter, different types of power reserves under Fingrid's ancillary services are described by looking at the underlying mechanics and rules related to the power reserves.

2.2.2 Power reserves

The power reserves are managed by the Nordic transmission system operators. The power reserves are an essential part of the electricity market, enabling safe and stable market environment. This chapter concentrates on the Finnish power reserve system maintained and operated by the national transmission system operator Fingrid.

Fingrid divides its power reserves into two different categories. The first category is called frequency containment reserve (FCR). It is mainly used for continuous frequency management. The second category is called frequency restoration reserve (FRR). These reserves are meant for two purposes, firstly they are meant for restoring the frequency to its normal state and secondly for releasing activated FCRs back into use. Typically there is also a third category for reserves called replacement reserves, however, these reserves are not in use in the Nordic power system. Illustration of above mentioned reserve types is shown below in Figure 2.6. (Fingrid, 2014)

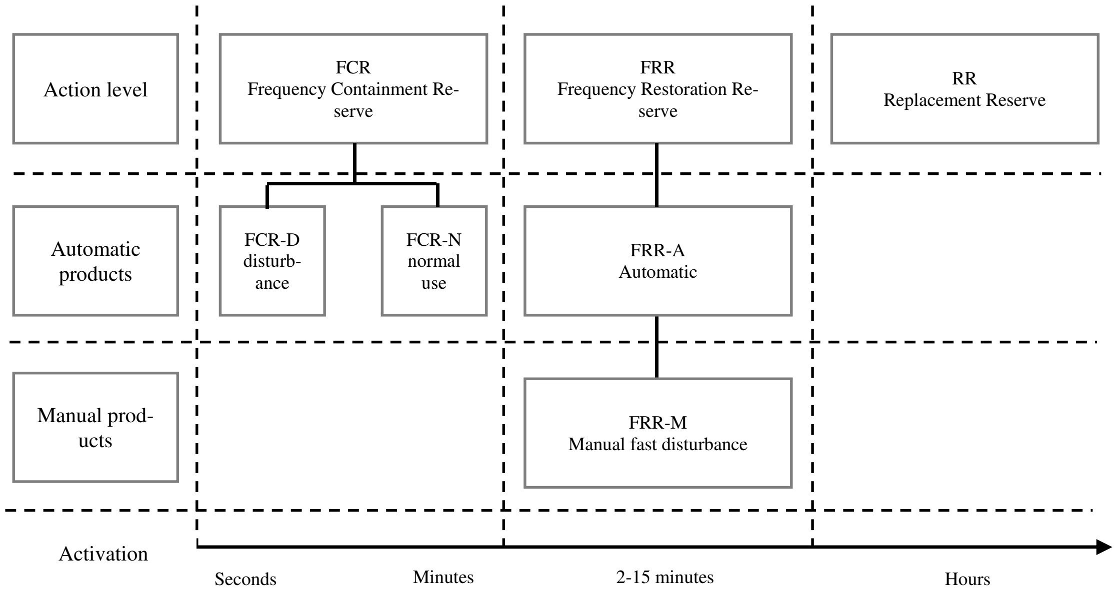

Figure 2.6 Illustration of different reserve types used by Fingrid. (Fingrid, 2014)

The FCR category contains two different reserves, the FCR-D and the FCR-N. The FCR-D is automated frequency containment disturbance reserve, whereas the FCR-N is automated frequency containment normal use reserve. Basically the reserves are divided by their intended purposes. The FCR-D is intended for frequency containment during disturbance scenarios, an example of a disturbance scenario would be case of unexpected disconnection of power plant or transmission line between two different areas. The FCR-N on the other hand is intended for frequency containment under normal usage. FCR-Ns main purpose is to maintain the power system frequency in the range of 49.9 – 50.1 Hz. From the technical requirement point of view the minimum reserve size for the FCR-N is 0,1MW and for the FCR-D 1MW. The activation time of the FCR reserves vary from immediate to 3 minutes. The requirements of the FCR reserves are listed in more detail in Table 2.2 (Fingrid, 2014)

Table 2.2 Requirement for FCR-type power reserves. (Fingrid, 2014)

Name	Minimum size	Type	Activation time
FCR-N	0,1 MW	Not defined	In 3 minutes
FCR-D	1 MW	Power plant reserves	5-30s
		Relay-connected loads	Immediately
		Idle reserve power machines	Not defined

Fingrid uses a domestic yearly and an hourly reserve markets to acquire the needed amount of FCR-type reserves. Reserve power holders may offer their power reserves to the yearly and/or the hourly reserve markets. Each of the market places have the same technical requirements for the reserve types and on both markets the underlying asset is the FCR-type reserves. The yearly market allows bidding once a year, and after that the price is applied for every day of the year to come. Respectively, on the hourly market, the price is formed every hour on every day of the year. Below in Table 2.3 the yearly and hourly markets are compared against each other. (Fingrid, 2014)

Table 2.3 Comparison of yearly and hourly markets for the FCRs. (Fingrid, 2014)

Yearly market	**Hourly market**
Bidding once a year (Fall)	To be able to participate the hourly market, the reserve holder signs a contract with Fingrid. This does not require participation to the yearly market.
It is not possible to participate in the middle of the agreement period	It is possible to participate to the hourly market in the middle of agreement period
Agreed amounts of reserve power will be purchased in full	Needed amount of power reserves will be purchased daily from the hourly market.
Reserve plans have to be submitted day-ahead by 18.00	Reserve bids have to be submitted day-ahead by 18:30
The market participant has a duty to maintain his reserves sold to the yearly market within his own capacity.	The reserve holders may submit bids of their supply daily. Market participant who already participates the yearly market can only attend the hourly market if he has already delivered the amount of reserve power defined in his yearly contract.
There will be a flat price throughout the year for the offered reserve power.	Payment will be defined by the most expensive bid used during the usage hour.

The other category is the FRR category. It consists of two types of restoration reserves, automatic and manual. The main purpose of this reserve category is to adjust the frequency back to normal operational levels and to release previously activated FCRs back into use. The technical requirements for participating reserves vary in this category depending on the type of the reserve. Automatic reserves have a minimum power requirement of 5MW of regulating power, wherein the manual reserves have a minimum amount of 10MW of regulating power. Furthermore the automatic reserves have an activation time of 2 minutes whereas manual reserves have a requirement of 15 minutes for the activation time. The FRR-A type reserves are procured through an hourly market where the reserve holders can submit offers for down- and up-regulating capacity. Respectively the FRR-M type reserves are procured through regulating market. The above mentioned requirements are listed in the Table 2.4 below. (Fingrid, 2014)

Table 2.4 Requirements for FRR-type reserves. (Fingrid, 2014)

Name	Minimum size	Activation time	Activation method
FRR-A	5 MW	2 min	Automatic
FRR-M	10 MW	max 15 min	Manual

For the year 2014 Fingrid had an obligation to have 1350 MW of reserve power. About 880 MW of this reserve capacity had to be acquired through the regulating market which means that there is a healthy market for power reserves. Rest of the reserve capacity requirement had to be fulfilled through the other power reserve channels.

The upkeep costs of these reserves are acquired from the transmission system tariffs and from the balance management service payments. Figure 2.7 illustrates the division between different reserve types and the obligated amounts of each reserve type. (Fingrid, 2014)

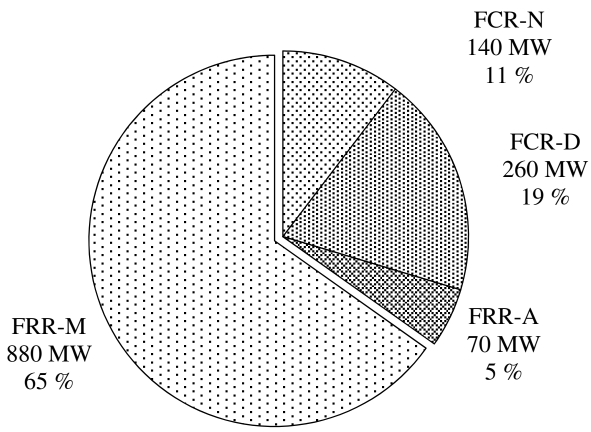

Figure 2.7 Illustration of reserve obligations for Fingrid for year 2014 (Fingrid, 2014)

This concludes the introduction of the ancillary market mechanisms. To recap, all the market mechanisms have been listed in

Table 2.5 below presents a summary of the ancillary market mechanisms operated by the Fingrid.

Table 2.5 Descriptions of ancillary market mechanisms

Ancillary market mechanisms	
Regulating market	Maintained and operated by Fingrid. The minimum bid size on the regulating market is 10 MW and the bids have to be submitted 45 minutes before the regulating hour. The power output of the participating reserves has to be verifiable in real-time and the reserve has to be able to activate in 15 minutes.
Power reserve: FCR-D	Automated frequency control reserve. Has yearly and hourly markets available, where reserve holders can submit offers. Minimum bid offer is 1 MW. Bids have to be submitted day-ahead the regulating hour/day. Submitted reserve can be a power plant with 5-30s activation time, relay-connected load with an immediate activation time, or an idle reserve power machine with immediate activation time.
Power reserve: FCR-N	Manual frequency control reserve. Has yearly and hourly markets available for resource holders. Minimum bid offer is 0,1 MW and the bids have to be submitted day-ahead of the regulating hour/day. There are no restrictions on the reserve type, but the reserve has to be able to activate in 3 minutes.
Power reserve: FRR-A	Automatic frequency restoration reserve. The reserves are procured through hourly market and the minimum bid size is 5 MW. The reserves have be able to activate in 2 minutes. The reserve type is restricted to hydro and heat generation.
Power reserve: FRR-M	Manually controlled frequency restoration reserve. Fingrid has FRR-M type reserves of its own, but the reserves can be also procured by Fingrid from the regulating market. The minimum offer size is 10 MW and it has to be able to be activated in 15 minutes.

Next chapter concentrates on the electrical imbalance management. Imbalance management is one of the most important tools in the electricity retailer's repertoire, since balance management is an essential part of daily operations when operating in the electricity market.

2.3 Balance management

Due to the physical nature of electricity the electricity generation and consumption have to be in perfect balance at every moment. This could be circumvented by using some form of electricity storage, but at the moment the cost efficiency of electricity storage solutions is very poor and storing electricity is generally not used. To be able to keep the electricity power system in perfect balance the electricity retailers and generators have to forecast their consumption and generation as perfectly as they can. However, the forecasts rarely realize exactly as planned and this will lead to situations where there is always surplus or deficit between the generation and consumption. To conquer this problem there are two procedures in place in the Finnish electricity market, the balance management and the imbalance settlement. (Partanen, et al., 2014)

Balance management and imbalance settlement procedures are operated in the Finnish electricity market by the national transmission system operator Fingrid, further on referred as TSO. From the perspective of grid reliability and integrity, the balance management procedure is the primary one of the two procedures. Fingrid is responsible for maintaining the power balance between electricity generation and consumption in Finland (Fingrid, 2014), and it should also be noted that the Finnish electricity market law Act 588/2013 (Finnish legislation, 2013) requires, that every party participating in the Finnish electricity market have to take care of its own power balance. This means that each party, be that electricity buyer or supplier, has to maintain a power balance between its electricity generation/procurement and consumption/sales at every moment. However, in practice the electricity market participant usually cannot do this by itself. This is why every market participant must have an open supplier whom maintains the power balance on behalf of the market participant. (Fingrid 2014)

The imbalance settlement procedure on the other hand is responsible for figuring out the open electricity deliveries between the market participants and the open suppliers. This procedure calculates the exact amount of electricity used by every market participant and manages the billing of surplus or deficit electricity. Both of these procedures are tightly linked to the regulating market introduced in chapter 2.4. The following sub-chapters describe the balancing power market and the underlying mechanics related to it. (Fingrid 2014, Partanen & al. 2014)

2.3.1 Managing generation and consumption

As stated before, Fingrid is the main responsible party in Finland for maintaining the power balance between electricity generation and consumption. Fingrid does this through balance management in co-operation with other inter-Nordic system operators. The main objective of balance management is to maintain the power system frequency at normal operational level. The power system frequency has been set to 50 hertz (Hz) in Nordic countries and it is permitted to vary between 49.9 Hz and 50.1 Hz. If the frequency decreases below 50 Hz to 49.9 Hz it acts as an indication of electricity consumption exceeding generation. Respectively, if the frequency ascends above 50 Hz to 50.1 Hz it is indication of electricity generation exceeding consumption. Fingrid maintains the power balance by using frequency controlled reserves and manual regulating as described in chapter 2.2. (Fingrid, 2014)

2.3.2 Balancing power market

Regulation power market in Finland is part of the Nordic balance power market and is maintained by the transmission system operator Fingrid. Fingrid operates the balancing power market, because it does not own enough regulating capacity on its own. To participate in the balancing power market the holders of controllable balancing power in forms of production or load control have to make a balance service agreement with Fingrid which gives them access to the balancing power market. (Fingrid, 2014)

To be qualified to be a balance responsible party, referred now as BRP, the holder of the balancing power must have 10 MW of controllable power which can be implemented in 15 minutes. This means that other market parties who own controllable balancing power and wish to participate in the balancing power market have to do it via their BRP or by signing a balancing power agreement with the TSO (Valtonen, & al., 2012). The price of the balancing power is formed for every consumption hour individually from the regulation bids sent by the BRP's. The principle in forming the price for balancing power is that when it is up-regulation hour the bids are arranged in a way that the cheapest bid is used first and respectively when it is down-regulation hour the most expensive bid is used first. This procedure is illustrated in Figure 2.8.

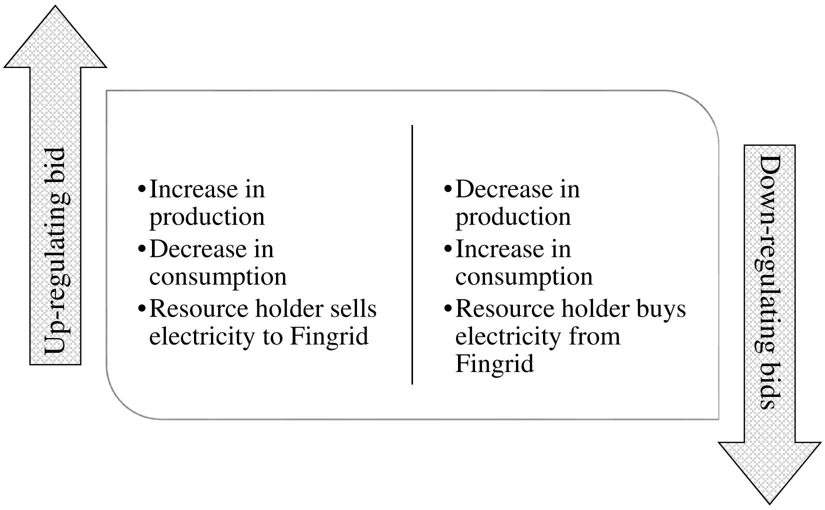

Figure 2.8. Illustration of the impact balancing bids have on production and consumption (Fingrid 2014)

Fingrid demands that the regulation bids are submitted 45 minutes before the specific consumption hour to the regulation power market. The regulation bids must contain the following information of the controllable regulation power in question:

- Amount of balancing power (MW)
- Price of balancing power (€/MWh)
- Type of balancing power e.g. consumption or production
- Transmission area where the balancing power resides
- Name of the resource in question, e.g. power plant, type of production, etc.

This information helps Fingrid to plan out the run order of the regulation power during the consumption hour in question. It should also be noted that the price of the regulation power acts as a basis for the imbalance power price. (Fingrid, 2014)

This chapter concludes the theory part consisting of introduction to electricity markets, which are used as a basis for the empirical part of this thesis. In the next chapter, the theories related to smart grids and demand response are introduced.

3 SMART GRIDS AND DEMAND RESPONSE

In 2006 the European Commission published a Green Paper titled as "A European Strategy for Sustainable, Competitive and Secure Energy" which declared that the Europe had entered a new energy era (European Commission, 2006). The proclamation was followed by six priority areas which should be addressed in order to lay out the foundation for the new European energy policy. The priority areas are listed below:

1. Energy for growth and jobs in Europe: completing the internal European electricity and gas markets
2. An Internal Energy Market that guarantees security of supply: solidarity between Member States
3. Tackling security and competitiveness of energy supply: toward a more sustainable, efficient and diverse energy mix
4. An integrated approach to tackling climate change
5. Encouraging innovation: a strategic European energy technology plan
6. Toward a coherent external energy policy

From these priority areas, among many other policies, emerged the initiative and vision for European Smart Grid. According to European Commission the vision was set to *embrace the latest technologies to ensure success, whilst retaining the flexibility to adapt to further developments.* This phrase in conjunction with the six priority areas made the basis for the Smart Grid research.

In 2011 European Commission published a Commission staff working document: Definition, expected services, functionalities and benefits of smart grids. The document describes the smart grids in general as follows:

> *A smart Grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety. – (European Commission, 2011)*

The National Institute of Standards and Technology (NIST) from United States of America describes the Smart Grid as an electric power system which has end-to-end integrated advanced communications infrastructure which provides consumers with:

> *Near real-time information on their energy use, support pricing that reflects changes in supply and demand, and enable smart appliances and devices to help consumers avoid higher energy bills. – (NIST, 2014)*

Some of the functionalities the European Commission and the National Institute of Standards and Technologies have envisioned for the Smart Grid are described next to give a better understanding of what the Smart Grid actually does mean.

The Smart Grid has been described by the NIST as more intelligent grid, which can for example to reduce the duration and frequency of power outages, facilitate efficient charging of electric vehicles, and provide more effective management of distributed generation and storage (NIST, 2014). While on the other hand the European Commission (EC) describes the Smart Grid through functionalities, such as enabling the network to integrate users with new requirements, enhancing efficiency in day-to-day grid operation, improving market functioning, and enabling and encouraging stronger and more direct involvement of consumers in their energy usage and management (European Commission, 2011).

In 2010 NIST drafted a Smart Grid concept model which acts as an architecture model for Smart Grid (NIST, 2010). Later on the Smart Grid Concept Model was modified by the EC Expert Group 1 which consists of the European Committee for Standardization (CEN), European Committee for Electrotechnical Standardization (CENELEC), and the European Telecommunications Standards Institute (ETSI) (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012). Below in Figure 3.1 is presented the latest Smart Grid domain group architecture made by the EC Expert Group 1.

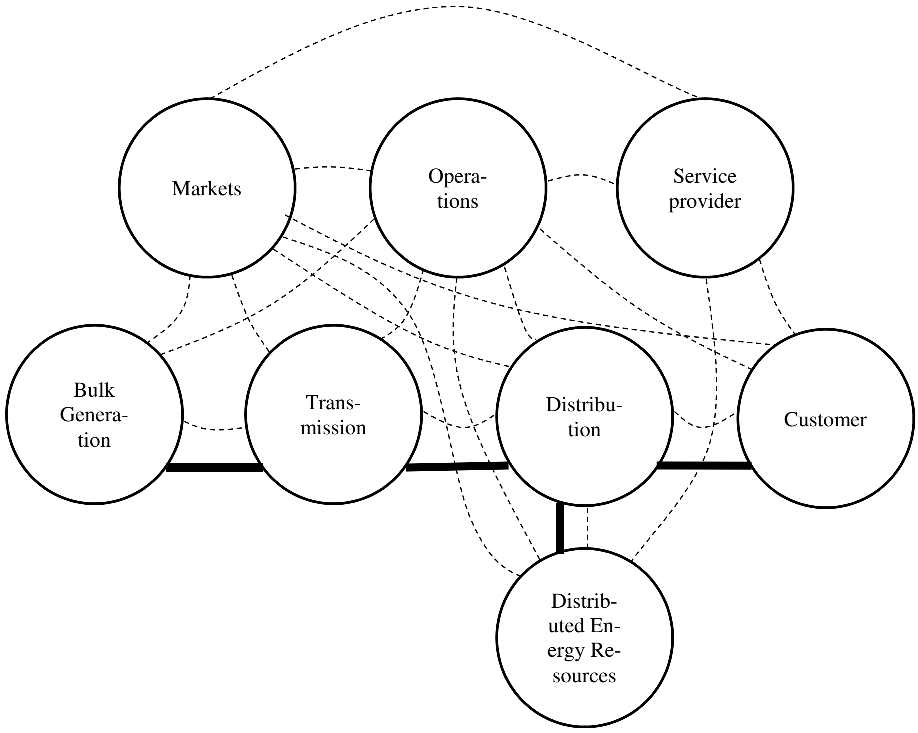

Figure 3.1 illustrates the Smart Grid architecture designed by the EC. The dashed lines illustrate secure communication flows, the solid lines illustrate electricity flow, and the circles illustrate different Smart Grid related domains. (CEN-CENELEC-ETSI Smart Grid Coordination Group, 2012)

The solid lines show the electrical flow across the system, while the dashed lines show the secure communication flows between different domains. The model adds a new domain to the classical electricity market model, the distributed energy resources domain, which illustrates the now growing amounts of photovoltaic- (PV) and wind generation. The Smart Grid concept model is a good illustration of how the future electricity grid is more and more enhanced by advanced communication structure while mainly retaining the "classic" electricity flow model. For more information and deeper architecture description can be found on the Smart Grid centric website of Institute of Electrical and Electronics Engineers (IEEE, 2014)

As this thesis concentrates on the service provider domain in the Smart Grid concept model, the next chapter discusses about service providers called aggregators and their main function Demand Response (DR).

3.1 Demand Response and Aggregation

Demand response or demand flexibility as an idea is quite old as it is closely tied to theory of supply and demand. Throughout the centuries several cases can be observed, where economists have described the nature of supply and demand. One of the earliest citations being from the fourteenth century (Hosseini, 1995). The theory of supply and demand itself can be described through the general laws of supply and demand written by Hubert D. Henderson in 1922. The three laws are:

1. When, at the price ruling, demand exceeds supply, the price tends to rise. Conversely when supply exceeds demand the price tends to fall.
2. A rise in price tends, sooner or later, to decrease demand and to increase supply. Conversely a fall in price tends, sooner or later, to increase demand and to decrease supply.
3. Price tend to the level at which demand is equal to supply.

The basics of demand Response can be defined as the second law of the general laws of supply and demand described above (Hendersson, 1922). However, when it comes to the supply and demand of electricity, the second law of supply and demand does not always hold true, as can be seen in Figure 3.2 below.

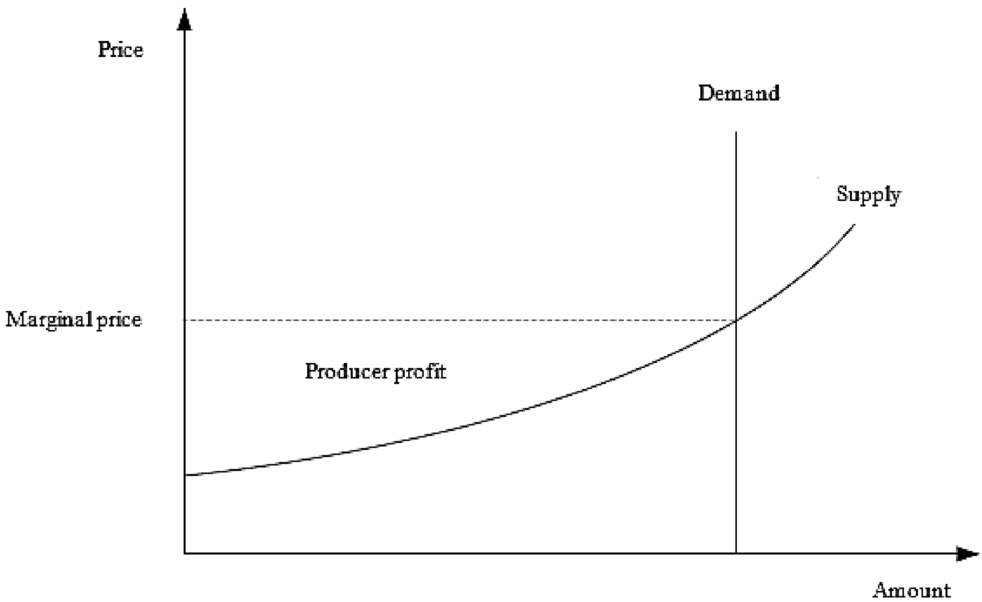

Figure 3.2 Illustration of inflexible demand, as it usually is the case with classic electricity markets. (Viljainen, 2013)

The main reason the second law of supply and demand does not always hold true when dealing with electricity markets is because there is a clear disparity between the wholesale electricity price and retail electricity price. By observing the wholesale electricity market prices and retail electricity market prices, one can clearly see that, while the wholesale price follows the actual supply and demand of electricity, the retail price is usually set to certain price level (Borlick, 2010).

This means that the price of the electricity to the consumer is always the same, despite what the actual demand or supply level of the electricity is. The retail price is usually set so that it comprises all the expenses of procuring electricity in the long term and because of this, the retail price does not react to short term changes. The difference between wholesale and retail market prices can be observed from Figure 3.3 below. The light line at the level of 0,08€/kWh presents the actual retail prices in Finnish retail electricity market, while the darker line illustrates the actual spot prices of the Finnish Elspot area prices in Nord Pool Spot. (Nord Pool Spot AS, 2014)

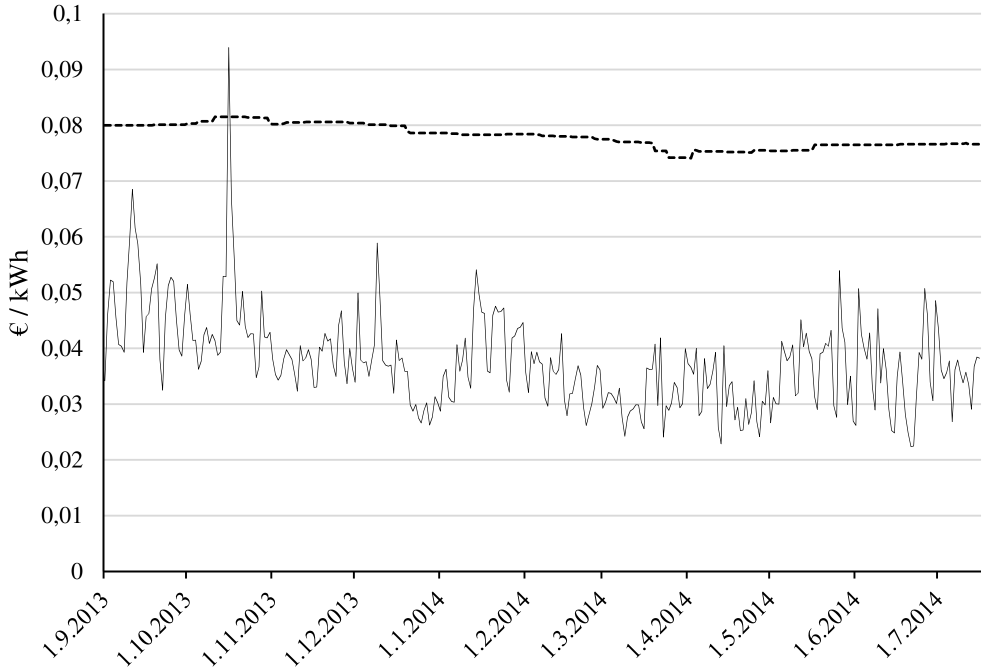

Figure 3.3. The difference between wholesale price and retail price illustrated. The dashed line illustrates what the inelastic retail price looks like and the solid line illustrates the changing wholesale

price of electricity in Nord Pool Spot FIN between September 2013 and July 2014 (Energiavirasto (Energy Authority), 2014; Nord Pool Spot AS, 2014).

The disparity described above is one of the reasons why DR adaptation has been slow in the area of electricity production and consumption (Torriti, Hassan, & Leach, 2010). Consumption of electricity has been classically seen as an inelastic demand mostly because of the predetermined price levels. Due to the predetermined price levels, the consumers does not see the price signals from the market, because the retail prices does not react to aforementioned short term changes in the market but instead stays flat as stated above. However, times are changing and the continued increase in smart meter penetration and the change towards the smart grids are driving the change for more dynamic pricing, such which follows the actual wholesale price, i.e. "smart rates" or "spot pricing" in retail markets. (Borlick, 2012)

3.2 Defining Demand Response and aggregation

Demand Response, as the name states, is a demand side response to something. By observing DR through the classic economic theories, DR could be described as an act in response to high prices due to limited supply. In this sense the consumer leaves the commodity into the store instead of buying it (Hendersson, 1922). This, however, is where the differences arise between classic commodities and electricity. Due to the nature of electricity and the nature how it is consumed, there are certain requirements for DR in the area of electricity consumption. For example, in North-America, a regional transmission organization (RTO) PJM Interconnection has defined that demand response act shall be defined as an act of reducing consumption explicitly as a response to market initiation signals. PJM states clearly in their fact sheet for DR that:

> *"Demand Response does not include the reduction of electricity consumption based on normal operating practice or behavior. For example, if a company's normal schedule is to close for a holiday, the reduction of electricity due to this closure or scaled-back operation is not considered a demand response activity in most situations". (PJM Interconnection, 2014)*

On the other hand Heshmati Almas describes Demand Response in his article "Demand, customer baseline and demand response in the electricity market", as follows:

> *"Demand response can be classified as change in electricity usage by end-users from their normal consumption patterns in response to changes in price of electricity overt time or as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is at risk of being jeopardized". (Heshmati, 2013)*

The need for the above mentioned specifications arises from the fact that the consumption of electricity usually fluctuates and varies greatly when observed hourly. Demand response can be justified by the growing amount of renewable energy resources in the future. Significant addition of renewable energy resources, such as wind power or solar generation, increases the fluctuation and unpredictability of electricity generation. Respectively, the increase in fluctuation and unpredictability also increases the need for frequency control and voltage control reserves on the transmission system operator's side. This increase is needed to secure the generation adequacy of the power system as described in the Eurelectric report on RES (Renewable Energy Sources) Integration and Market Design. (Eurelectric, 2011)

3.2.1 Demand response classifications

The most typical use-cases for DR are peak shaving in the electricity market and ensuring system stability during critical peak hours. Using these use-cases as basis for the type-definitions of DR the DR can be usually divided into three major groups. Other way of defining the DR type-definitions would be analyzing the source of the controlling signal (Boait, Ardestani, & Snape, 2013). However, in this thesis the division into three groups is used because of the relatively easy tie-in it provides with the Finnish electricity market in mind.

The first group is defined as Economic DR (Heshmati, 2013; PJM Interconnection, 2014). As the name suggests, this type of DR is closest to the classical economic demand response from the fundamental point of view. Economic DR is aimed at performing day-in day-out in the electricity market and the typical use-case for this type of DR is peak shaving. The activation signal for economic DR comes from the electricity market in a form of price signal (Department of Energy & Climate Change, 2012)

The second group is defined as Emergency DR (Heshmati, 2013; PJM Interconnection, 2014). This type of DR is aimed at performing during critical peak hours. What this means, is that when the electricity distribution grid is experiencing crippling congestions emergency DR is applied. Whereas Economic DR is dispatched numerous times during a day, Emergency DR is typically dispatched a few times per year, according to PJM's Emergency DR Load report (PJM Interconnection, 2012). The source of the activation signal for Emergency DR can vary, but the signal is typically initiated by some kind of electricity grid related emergency, hence the name Emergency DR (Department of Energy & Climate Change, 2012; PJM Interconnection, 2014)

The third category is called Ancillary DR. Ancillary DR category is meant for supporting tasks related to electricity grid reliability. Ancillary DR Category differs from Emergency DR category in such regard that it is meant for more active usage in grid stability related tasks. The main tasks ancillary DR resources are used are, for example frequency containment and grid voltage regulation. The source for ancillary DR Service activation signal can be from TSO or DSO, depending on what part of the electricity grid is being focused on. As a summary, the differences between the characteristics of Economic DR, Emergency DR and Ancillary DR are listed below in Table 3.1. (Fingrid, 2014; PJM Interconnection, 2014)

Table 3.1 Type definitions for Economic, Emergency and Ancillary Demand Response services. (Department of Energy & Climate Change, 2012; Fingrid, 2014; PJM Interconnection, 2014)

Type of DR	**Defining characteristics**	**Source of activation signal**
Economic DR	Enacted during "peak shaving hours". Occurs day-in day-out.	Electricity market
Emergency DR	Enacted during "critical peak hours". Occurs few times a year.	Varies. E.g. TSO, Capacity market.
Ancillary DR	Supports electricity grid reliability and usability tasks, such as frequency control and grid stability.	Depends of the operating area, could be TSO or DSO.

Next chapter discusses aggregators and their roles in relation to demand response. The examples presented in the next chapter are from the North American market and specifically from the PJM Interconnection.

3.2.2 Aggregator

Aggregation is an act of collecting smaller individuals into one bigger actor. This is the basic function of an aggregator. The need for an aggregator in relation to demand response comes from the market restrictions usually associated with electricity markets. Aggregator's function is to act as an agent between the electricity market and the demand side load (DSL) also known as demand response load. The aforementioned market restrictions usually prohibit smaller loads from participating in the markets.

For example, in PJM Interconnection, the minimum size of participating load is 0,1MW or 1MW depending on the market in question (PJM Interconnection, 2014). This market restriction is not usually an obstacle for conventional power generation or heavy industry participating in demand response programs, but smaller loads like commercial buildings and households can find the restriction limiting their access to the market. Therefore the aggregator is usually needed in between the market and the participating DR load. As previously mentioned, the aggregator pools up the smaller loads to create a single entity which has enough DR capacity in order to overcome the market restrictions and to participate to the market (Vasirani & Ossowski, 2013). Below in Figure 3.4 is presented a possible model for aggregator positioning in relation to the electricity market, electricity retailers and demand side loads.

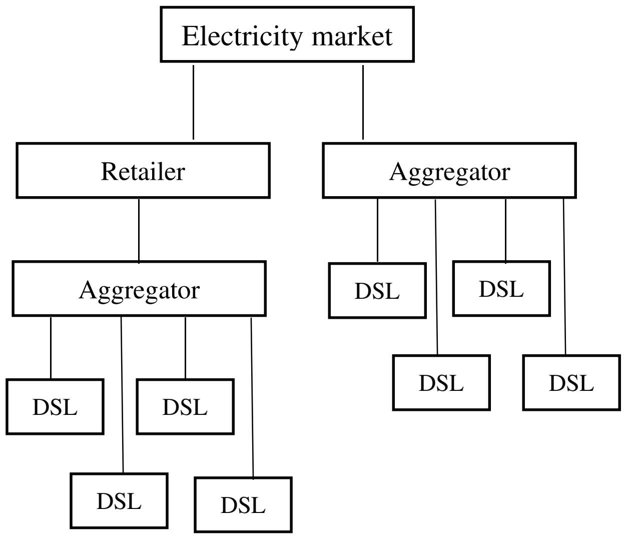

Figure 3.4 shows two alternative positions for the aggregator in relation to the market. Adapted from (Vasirani & Ossowski, 2013)

The aggregator can act as an independent market actor or as a service provider for the electricity retailers as illustrated in the Figure 3.4 above. When the aggregator acts as an independent market actor he acts as an interface between the DSLs and the market operator. The aggregator collects the DSLs into a group and presents them as a single entity to the market. Depending on the market structure the aggregator might be an already existing market participant, such as a system operator or a load serving entity. (Parvania, Fotuhi-Firuzabad, & Shahidehpour, 2013)

In the other market model, presented on the left side of the figure 3.4 the aggregator collects the DSLs into a single entity and presents them to the electricity retailer, who then presents them to the market according to his market position. In this aggregation model the aggregator acts as a service provider for the electricity retailer and optimizes the DR resource activation according to the electricity retailer's preferences.

This thesis concentrates on the aggregator model where the aggregator acts as a service provider under the main electricity market participant. The discussion related to the service provider aggregation model continues in a chapter 4 where the Demand Response service for active balance management is introduced.

In the next chapter the enabling technology behind Demand Response is discussed. The chapter looks at the AMI-technology from the legislative point of view as well as from the technical point of view.

3.3 Smart Meters

One key aspect in enabling Demand Response in the Smart Grid environment is the technology. The technology chosen for this task is called Advanced Metering Infrastructure (AMI), commonly known as Smart Metering. (Aidon, 2014; (Kamstrup A/S, 2014; European Commission, 2014)

In Europe, the European Commission has set roll out target for 80% of the consumption sites in the EU by 2020. This was set by EU in the Third Energy Package, which requires: "Member States to ensure implementation of intelligent metering systems for the long-term benefit of consumers." Commission report COM(2014) 356 Final, which follows the smart metering deployment in the EU-27, states that by 2014 already 45 million Smart Meters have been installed in the EU. (European Commission, 2014)

In order to achieve an efficient roll-out of Smart Meters, the European Commission has set a list of functionalities which it considers as key Smart Meter functionality. The key Smart Meter functionalities are listed in a Table 3.2 below. The presented list has acted as a basis for the legislation considering Smart Metering in the EU member states and has strongly shaped the actual functionality of the Smart Meters. (European Commission, 2011; Energiateollisuus, 2010)

Table 3.2 Key Smart Meter Functionality set by the European Commission. (European Commission, 2011)

Key Smart Meter Functionality	
Domain	**Functionality**
For the customer	1. Provides readings from the meter to the customer and to equipment that he may have installed
	2. Updates these readings frequently enough to allow the information to be used to achieve energy savings
For the Meter operator	3. Allows remote reading of meter registers by the Meter Operator
	4. Provides two-way communication between the meter and external networks for maintenance and control of the meter
	5. Allows readings to be taken frequently enough to allow the information to be used for network planning
For commercial aspects of energy supply	6. Supports advanced tariff systems
	7. Allows remote ON/OFF control of the supply and/or flow or power limitation
For security and privacy	8. Provides secure data communications
	9. Fraud prevention and detection
To allow distributed generation	10. Provides import / export & reactive metering

3.3.1 Technical implementation model of the AMI infrastructure

The technical implementation of the Smart Meter infrastructure was left up for the Original Equipment Manufacturers (OEMs). Every OEM has their own way of implementing the system, but in principle the AMI-systems on the field can be presented by following the structure illustrated in Figure 3.5. (Järvinen, 2014)

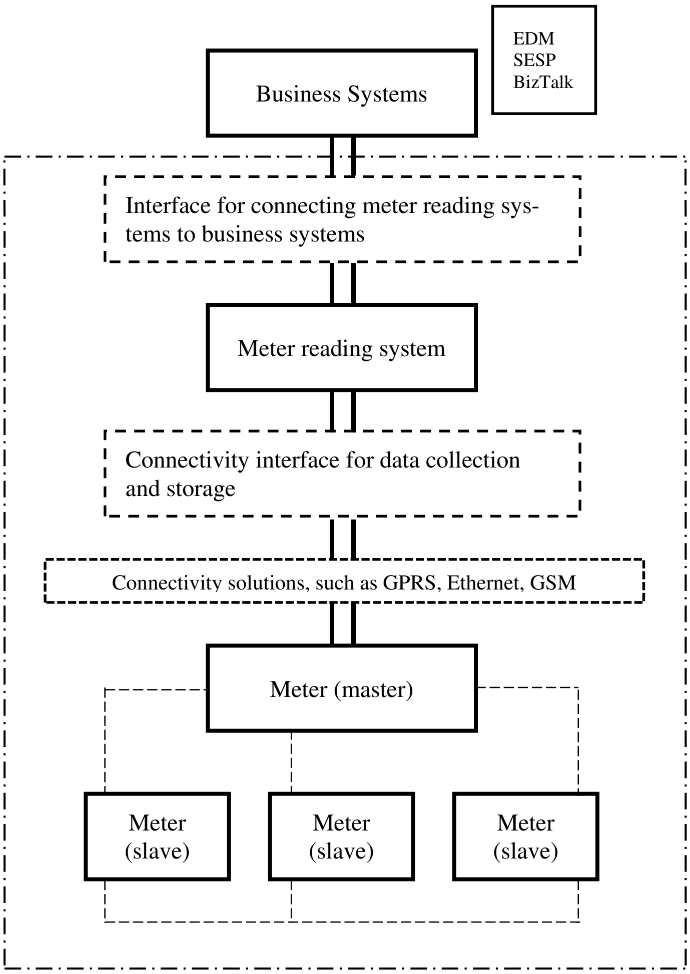

Figure 3.5 Common AMI-implementation structure (Järvinen, 2014)

First block in the AMI-implementation architecture is the Business Systems, which actually are not part of the AMI-system. The Business Systems are the backend systems of the Smart Meter operators and usually consist of systems such as Energy Data Management (EDM) systems or Energy Management systems (EMS). The Business Systems are connected to the AMI-infrastructure via an interface which acts as a translator between the two systems. (Järvinen, 2014)

The second block of the AMI-infrastructure is the Meter reading system. This systems connects to the Smart Meters and handles different tasks, such as reading and controlling of the meters. The meter reading system has a connectivity interface for data collection and storage, which can also be used for meter control. Through the connectivity interface the meter reading system connects to the master meters via various connectivity solutions, such as General Packet Radio Service (GPRS), Ethernet, or Global System for Mobile communications (GSM). These connectivity solutions are usually provided by an external data connectivity provider. (Järvinen, 2014)

The third block of the AMI-infrastructure is the Master Meter, which can be considered as a concentrator which collects data from the meter connected to it. The meters connected to the Master Meter are called Slave Meters and these are the meters which are usually installed at the consumers' premises. The master and slave meters are connected to each other by various methods and the method used depends on the meter type and the environment. Most common methods for connecting the slaves to the master meter are protocols such as RS 485, LON/PLC, Meshnet™ and different short range radio networks. (Aidon, 2014; Järvinen, 2014)

This chapter concludes the theory part of the thesis. In the following chapters the AMI-system is observed through an use case, which was created for the sole purpose finding out the limitations and challenges in AMI-systems. After the use case has been defined and presented, the capabilities of the AMI-system are compared against the use case. If challenges or bottlenecks in AMI implementation are found by analysing the AMI-system against the use case, then alternative solutions and models are suggested to encounter the challenges.

4 DEFINING AND TESTING MULTILAYERED DEMAND RESPONSE SERVICE IN AMI-ENVIRONMENT

The need and reasoning for a service called multilayered demand response service comes from the need to manage electrical imbalances in a market environment, where electricity generation is moving from centralized generation to decentralized generation while at the same time the electricity generation methods are moving towards RES. This change is already visible in Germany and is expected to reach other countries as well. The change to RES and variable generation empathizes the importance of imbalance management mechanisms such as Elbas and regulation market. When the uncertainty increases in electricity procurement and the predictability of the electricity generation becomes more difficult and the need for right tools, which can manage imbalance regulation, grows. (Karnitschnig, 2014)

To manage the imbalances caused by the variable electricity generation, the utilization of demand response becomes a worthy possibility. Using AMI-infrastructure for delivering demand response in form of services such as demand response balance management tools are already a possibility. This thesis tests the capability of the current AMI-systems in a fictional demand response environment called a multilayered demand response service.

In order to test how capable the current generation AMI-infrastructure is, the system is introduced into this state-of-the-art demand response environment. The multilayered demand response service environment is aimed towards the electricity retailers, who can utilize the service to limit their exposure to the imbalance risk. The origins of the multilayered demand response service are in the ITEA 2 SEAS project where the service is envisioned as one of the use cases for the project.

The use case utilized as the basis of the multilayered demand response service describes the above mentioned imbalance management tool for electricity retailers for the day-ahead electricity market in Appendix B. The multilayered demand response service concept created in this thesis concentrates on the balance management functionality, which is the core functionality of the service. In real life, when speaking of demand response service, the service would include several other parts, such as the following:

- Load aggregation on behalf of the customer
- Load control accordingly to customer's wishes
- Information relay between market parties, for example from customer to load
- Billing and balance management for the participants

In this thesis the core functionality of the service, the balance management through demand response is emphasized and therefore the other parts of the service have been focused to a lesser extent. The service and use case was designed with the Nordic electricity market in mind, but it could be modified for other electricity markets as well, simply by redefining the parameters and boundaries to match the target market.

This thesis takes the basic use case and expands it by adding more layers to it, this way forming a multilayered demand response service. By creating a very demanding and challenging demand response environment, a more diverse testing use case is achieved and the limits and bottlenecks of the current AMI-infrastructure are noticed better.

In the following chapters the outlines of the extended demand response service are drawn. The methods used for designing the environment and the final structure of the service are presented to give the reader an accurate description of the multilayered demand response service. The following chapters also describe the testing setup used to test the AMI-infrastructures capabilities and in the end a hypothesis of the results is formed based on the current knowledge.

4.1 Constructing the multilayered demand response service model

The base use case utilized in this thesis was constructed as a part of the ITEA 2 SEAS project task 1.1 and task 1.2 where scenarios and use case definitions were created, and markets and business models related to the scenarios were analyzed.

The base use case was created by utilizing a use case template provided by the SEAS consortium.

The use case template consists of 8 different categories which describe the use case's functionality and features. The categories contain descriptions of general information related to the use case, contextual settings where actors and resources are defined, functional description of the use case, non-functional description of the use case, business properties, constraints related to the use case, possible threats and exceptions and other relevant information related to the use case. For more detailed and informative look of the use case template, refer to the Appendix A SEAS use case template.

The base use case in itself describes a way to utilize existing AMI-systems and Home Energy Management systems (HEMS) for controlling and managing flexible loads in the Nordic day-ahead market Elspot. The use case proposes that the functionality is to be used as an imbalance management method by the electric retailers on the Elspot market. This thesis concentrates on the AMI-system utilization in the constructed use case and expands on that model. The original use case is presented in Appendix B.

Where the use case constructed in the SEAS project concentrates on the day-ahead market, the use case utilized by this thesis is expanded on multiple markets. The markets are described as layers of the demand response service and each layer is defined by how close the activation time of the resource is to the consumption hour. The next chapter describes the layers of the multilayered demand response service and presents the parameters which define each layer.

4.1.1 Description of the layers in the multilayered demand response service model

The multilayered demand response service expands onto 7 different layers. This means that there are 7 different earning principles which the electricity retailer can utilize in his imbalance management strategy. The layers divide into two categories based on the market type and which organization operates the markets. The first category is described as Nord Pool Spot operated markets, which include the Elspot and the Elbas markets introduced in chapters 2.1.1 and 2.1.2. The second category is described as the ancillary markets operated by the Fingrid. These markets were introduced in chapters 2.2.1 and 2.2.2. The categorization is presented below in Table 4.1.

Table 4.1 Categorization of the market layers in the multilayered demand response service

Nord Pool Spot organized markets	• Elspot • Elbas
Fingrid organized markets	• Regulating market • Power reserve: FCR-D • Power reserve: FCR-N • Power reserve: FRR-A • Power reserve: FRR-M

Each of the market layers is defined by a certain set of parameters. The parameters illustrate the properties the market layer is portraying. The parameter list consists of the following parameters:

- Minimum bid size
- Gate closure time for the bids
- Resource activation time requirement
- Technical restrictions

To construct a clear structure for the multilayered demand response service the market levels are analyzed from a time critical viewpoint. However, when analyzing from a time critical viewpoint the Nord Pool Spot and Fingrid operated markets differ from each other. The Nord Pool Spot organized markets have a gate closure time and the delivery of the physical electricity is expected to happen on the consumption hour, whereas the Fingrid operated markets have a gate closure time for bids and a resource activation time requirement for physical delivery.

This incompatibility created by the different operation manners create a need to unify the time model used to form the timeline of the different layers. As the market models differ greatly from each other it is proposed to unify the time parameters of the markets by using the gate closure time with the Nord Pool Spot operated markets and the activation time with the Fingrid operated markets.

The suggestion of unifying the time parameters in this way can be justified by the differing market models in the Nord Pool Spot and Fingrid markets. In the Nord Pool Spot markets the activation moment is always known and rarely, if at all, causes readiness problems for the generators. However, on the Fingrid markets, where the reserves are procured for a fixed amount of time, but only activated when needed, the activation time becomes dominating parameter. By unifying the time critical parameters the market model for the multilayered demand response service takes the following structure illustrated in Figure 4.1.

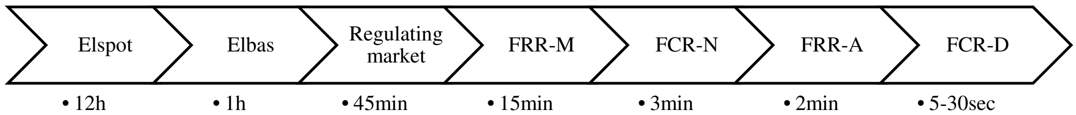

Figure 4.1 Model for multilayered demand response service. In this illustration the layers are shown as a timeline which starts at the Elspot layer and ends on the consumption hour.

This structure will be used as the model for the multilayered demand response service. The model for the service enables the user of the service to exploit all the available market levels to get the most out of his/hers flexibility resources.

4.1.2 Restrictive parameters and extending the service model

As the real world markets used as the basis of the layers, which the multilayered demand response service will be constructed of, are not really designed to be a layered entirety, there are few parameters which still need to be taken into account. In addition to the time critical parameters, there are parameters which are described as restrictive parameters.

The restrictive parameters are outlined in this thesis to technical parameters as they relate to the technical side of the AMI-infrastructure and due to this reason parameters, such as market type and bidding mechanisms are left outside of the scope. The additional parameters defined as restrictive parameters are the minimum bid amount and the market related technical restrictions. These parameters extend the model of the multilayered demand response service presented in Figure 4.1and form the extended model. The extended model of the multilayered demand response service is presented below in Table 4.2.

Table 4.2 Extended model for multilayered demand response service.

	Elspot	*Elbas*	*Regulating market*	*Power reserve: FRR-M*	*Power reserve: FCR-N*	*Power reserve: FRR-A*	*Power reserve: FCR-D*
Time parameter	12h	1h	45min	15min	3min	2min	Instant, 5-30sec
Minimum bid amount	0,1MW	0,1MW	10MW	10MW	0,1MW	5MW	1MW
Technical restrictions	none	none	Power output has to be verifiable	Manual control	none	Automatic control Hydro and heat generation only	Power plant, relay-connected loads, idle power machines only

The added restrictive parameters introduce more challenging environment mainly for the Fingrid operated layers in the form of quite challenging bid amounts and in the case of FRR-A power reserve few technical requirements for the loads are introduced, which could cause incompatibility between the market and current AMI-systems. This extended model for the multilayered demand response service will be the final model the AMI-infrastructure is tested against.

4.2 Pairing AMI-technology with the multilayered demand response service model

To analyze the capabilities of the AMI-infrastructure and to tackle the first research objective of the study, the AMI-infrastructure has to be paired with the multilayered demand response service model. This chapter describes the AMI-system used in the testing and the testing methods.

4.2.1 Description of the testing setup

As it would have been impossible to build a working AMI-prototype platform for solely testing purposes an existing system was used as an illustrative model. The existing system was in production and the services provided via this platform were relied on by the customers of Empower IM, the system was not directly used. However, the system has been executing actions and producing data which resembles the actions intended to be used in the above described environment, so this data was used instead. It should also be noted that the testing setup consisted of only one system by one manufacturer, thus the results do not represent a situation where one DSO might have several systems in use.

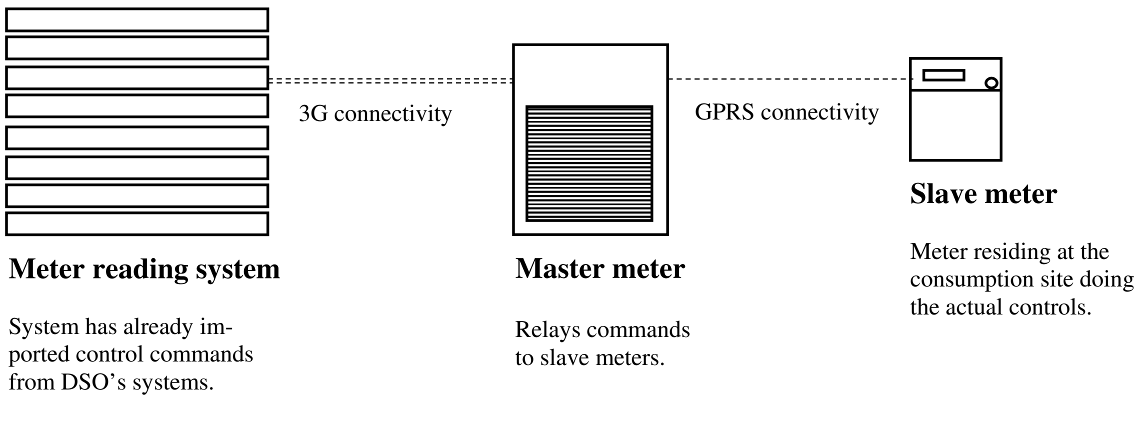

Figure 4.2 Illustration of the testing setup used in the demand response simulations.

The system used as a portrait for the current AMI-systems is built on an architecture which is similar to the one presented in figure 4.2. The part of the system utilized in these tests consisted of integration platform in addition to the meter reading system and the meters. The integration platform continues the AMI-system from the one presented in Figure 3.5 by adding a Microsoft BizTalk server and a DSOs Customer Information System (CIS) to the chain. (Empower IM, 2014)

The data provided by the AMI-platform consisted of remote connect and –disconnect information, which was used to simulate the control commands needed in demand response, and of failure reports in meter reading, which were used to simulate the robustness of mass communication needed in delivering demand response control commands to the loads under the aggregators command.

The remote connect and –disconnect data consisted of following action chain when exchanging information in the AMI-system described earlier:

- Integration platform sends the connect and disconnect commands to the meter reading software
- Meter reading software sends report of control actions to the integration platform

Normally the action chain would consists of few additional steps, such as communication with the DSO. However, these steps were stripped of the action chain as they would not serve any meaningful purpose when analyzing the data against the multilayered demand response service. It could be argued that the communication with the DSO could simulate the communication between the AMI-system and aggregator, but as the DSO does not execute actions such as aggregation, the data would not represent the actual communication between aggregator and the AMI-system. The stripped data, which was used for the analysis, consisted of the run times of multiple remote connect and –disconnect actions over a period of one year.

The second information resource, the failure reports which would be used to simulate the robustness of the AMI-system under heavy loads, were collected from three different geographical areas over the period of 8 days. These reports consist of data reporting the reliability of the system for each day at the 12 h mark and at the 84 h mark of the initiation signal for the meter reading.

These data streams were then enhanced by interviewing experts in the field of AMI-technology from managing positions to the operators and leading experts. The interviews were carried out both in face to face meetings and via email. The experts were asked questions related to their working area and ranging from identifying known bottlenecks and weaknesses in the system to other restrictive matters, such as the operating environment.

The above described three research methods were then combined when analyzing the data and the results of this analysis are presented in chapter 5.1.

5 FINDINGS & ANALYSIS

This chapter concentrates on presenting the results gained through analyzing the data, and explaining the results by utilizing the insights gained from the expert interviews. The results are then analyzed to identify major problems with the pairing of the multilayered demand response service and the AMI-platform. After the major challenges have been identified this chapter proposes possible solutions to solve the problems found in the analysis phase.

5.1 Analyzing the AMI-data in multilayered demand response environment

The analysis of the AMI-data is divided into three parts, which are used as basis for the conclusions drawn in this chapter. The first part of the analysis concentrates on comparing the carry-out times of demand response commands against the market structure of the multilayered demand response service.

In the second part of the analysis the robustness of the AMI-system is simulated and analysed in a demand response environment. The third part of the analysis concentrates on the operational environment of the demand response service and leans on the expert interviews and literature available.

After analyzing the three data and information sources a conclusion is drawn which identifies the major challenges hindering the multilayered demand response service in an AMI environment.

5.1.1 Analyzing the carry-out times of demand response commands

In the first part of the analysis the remote connect and –disconnect data was used. In order to make the data usable it had to be cleared of failed connecting attempts. After clearing the data, the remaining data was used to illustrate the run times of demand response commands by utilizing the remote connect and –disconnect run times. Figure 5.1 below illustrates the remote connect and –disconnect run times gained from the data.

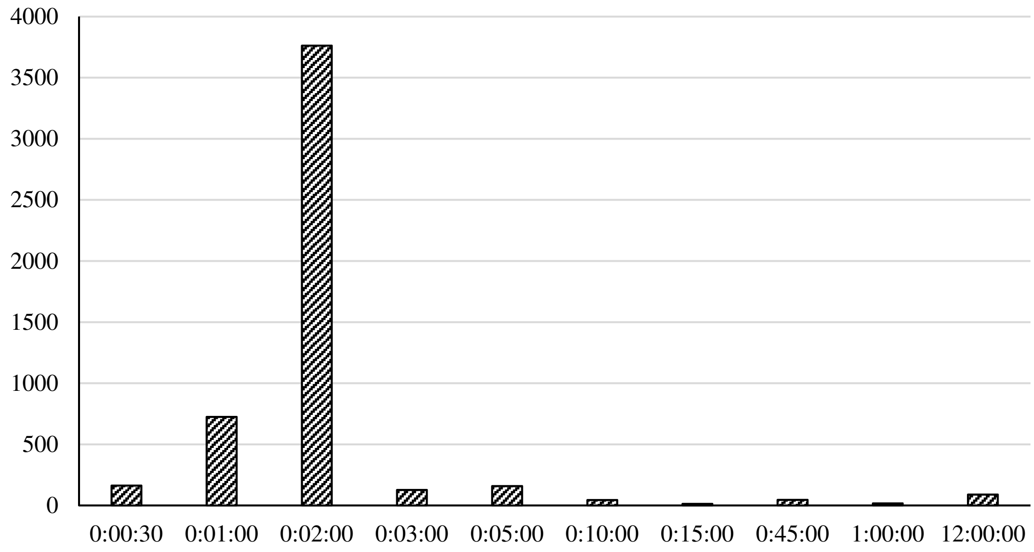

Figure 5.1 Running time for single remote connect and disconnect actions illustrated. (Empower IM Oy, 2014)

The run time results illustrated in Figure 5.1 were collected from over 5000 cases, which were arranged into an order from shortest run time to longest run time. The intervals used to illustrate the different classes are the time parameters gained from the multilayered demand response service model. This was done in order to truly illustrate the capabilities of the meters in the actual state-of-the-art environment. As can be seen from the Figure 5.1 most of the meters are capable of carrying out the demand response command under the 2 minute mark, and another significant group of 300 meters can manage the task by the 5 minute mark. Outside the main groups, even the slowest meters are still able to carry out the demand response commands by the 12 hour mark, which is the most modest time parameter in the multilayered demand response model.

Additionally to illustrate the saturation of the run times, the data was arranged to a cumulative series. Figure 5.2 illustrates the saturation of the run times by using the time parameters from the multilayered demand response service model as the class goals. The successful run times seem to saturate at the 10 minute mark.

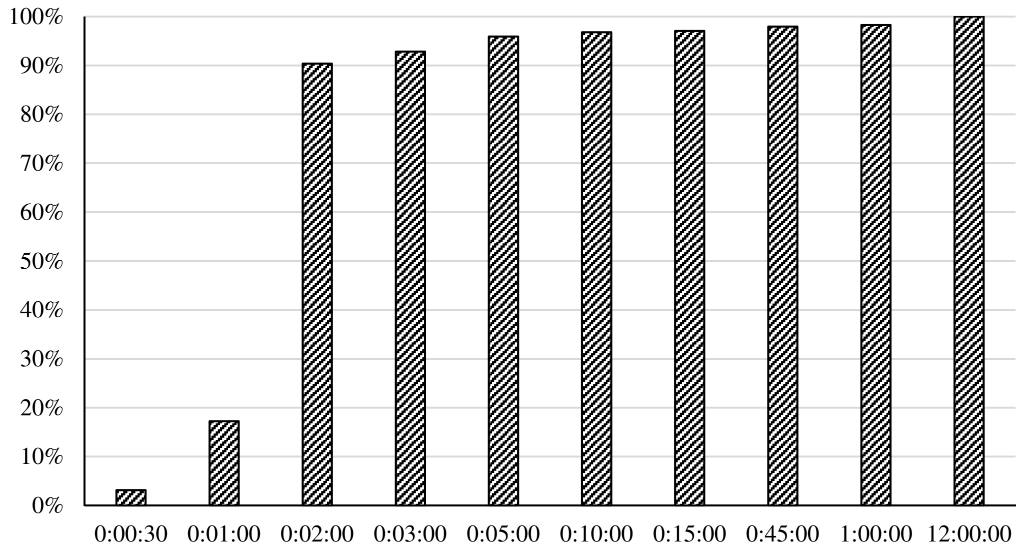

Figure 5.2 Illustration of cumulative single remote connect and disconnect request actions. Most of the meters have successfully carried out the control request by the 10 minute mark. (Empower IM Oy, 2014)

By interpreting the Figure 5.1 and Figure 5.2 it can be said, that the current generation of AMI-devices are capable of carrying out demand response commands at even the most challenging market levels. To get a clearer picture of the actual performance level of the demand response the raw data has to be paired with the multilayered demand response service model.

Table 5.1 presents the multilayered demand response model from the viewpoint of the time parameters and the remote connect and –disconnect run times have been adapted to the classes formed by the time parameters. By examining the results presented in Table 5.1 it can be deduced that 90 % of the meters can manage the second most challenging layer in the multilayered demand response service model, the FRR-A layer.

Table 5.1 AMI-meter performance compared against different layers of the multilayered demand response service.

Market	*FCR-D*	*FRR-A*	*FCR-N*	*FRR-M*	*Regulation market*	*Elbas*	*Elspot*
Time parameter	30 s	2 min	3 min	15 min	45 min	1 h	12 h
Percentage of meters - *amount*	3 %	87 %	2 %	4 %	1 %	0 %	2 %
Percentage of meters - *cumulative*	3 %	90 %	93 %	97 %	98 %	98 %	100 %

However, what the data does not show is that the average time for one demand response control command was approximately 1 minute 20 seconds. It should also be noted that in order to get this result the data had to be cleared of clear outlier results. The outlier results were run times which clearly differentiated from the mass, such as run times of 12 hours.

It should also be noted that the run times consist of only load control commands and the change of state actions carried out by the AMI-meters. When considering demand response in broader perspective, the load control command have to be preceded by some sort of an aggregation procedure. When calculating the total run time for demand response control commands, the aggregation and electricity market related actions, such as price checking and bid making should also be included to the total run time.

Figure 5.3 illustrates the additional aggregation block which should be taken into consideration when calculating AMI control command run times and especially when comparing the run times against the layers of the demand response service model. The solid arrows in the Figure 5.3 illustrate the part where the data has been acquired and the dashed line illustrates the aggregation part which has to be added to the carry-out times when comparing the data against real world environment.

Figure 5.3 Dashed line shows the additional block formed by the aggregation process, which has to be taken into account when designing a demand response service in a time critical market environment. The average process time of 1 minute 20 seconds gained through the data-analysis only consists of load control and change in state blocks.

When looking at the data and taking into account the aggregation part of demand response control commands the final run time for demand response control command should be somewhere of 2-5 minutes. Now, this begs a question, why does it take 45 minutes to 12 hours for some of the meters? Initial analysis of the data suggests that there might be some sort of a bottleneck limiting the carry-out time of the demand response control commands.

To get a clearer picture of the situation and to find an explanation to the slower carry-out times, the matter was brought up in the interviews held for the experts in the field of AMI-technology. The problem was known and acknowledged by the experts, but finding a clear or simple explanation to the problem proved to be difficult. However, the experts interviewed suggested that one possible explanation could be the permutation of the systems on the field.

As described in chapter 3.3 the AMI-systems are a formation of many different systems. If the analysis of AMI-systems is started from the top-level systems, there may be multiple CIS, EDM and EMS software solutions and products and they all vary from DSO to DSO. When moving one step lower to the meter reading level, again, there are various systems on the field from various meter manufacturers. In one case, it was discovered that at one point of time, one specific DSO had 5 different meter reading systems in use at the same time, as they had meters from 5 different manufacturers. Considering that each of the systems use different file formats and protocols for data exchange, integrating the systems into one collective identity is challenging. (Oksanen, 2014)

One step further down, from the meter reading systems are the actual smart meters. Even if the DSO had only one metering system from only one manufacturer, there may still be various metering models, from various time periods which causes the meters to be incompatible with each other to certain point. For example, the connectivity methods used in the meters have evolved over time. At the moment, there are several connectivity methods in use and some of the meters utilize a connectivity method called Power Line Communication (PLC), which may take up to 15 minutes to communicate with, while more modern meters utilize the GPRS, which enables the meters to communicate with the meter reading software within a matter of seconds. As pointed out earlier these are the results of having meters from different time periods. The reason why DSOs have meters from different time periods is that the meter installation or roll-out projects as they are called, are long and time consuming. One project may take up to few years, and usually when the project is finished, new meter models have already been introduced to be used in the next roll-out projects. (Oksanen, 2014)

Naturally, a combination of multiple different systems cannot work with each other without integration solutions. Multiple upper-level systems, various meter reading systems and even different meters need to be integrated to the most critical parts of the system. The added integration layers add to the complexity of the system and usually cause problems for the performance of the system. The experts suggest that behind the varying carry-out times is the varying performance of different systems and the complex integration solutions which act as additional layers between the communication paths. (Järvinen, 2014; Komi, 2014; Oksanen, 2014)

5.1.2 Simulating the robustness of AMI-technology

Next, the robustness of the AMI-system was analysed when paired with the multi-layered demand response service. The data was gathered from three geographically different locations as described earlier in chapter 5.1.1. Since it was not possible to test the robustness of the system in a demand response environment, the robustness was tested by utilizing robustness data from mass meter reading. The use of this data was suggested in the interviews by the experts as the meter reading phase really puts the connections and the whole system under stress. The results from the mass meter reading are presented in Table 5.2 below.

Table 5.2 Successful meter reading rates from three different geographical areas with two different deadlines for the meter reading actions. (Empower IM Oy, 2014)

	Area 1	**Area 2**	**Area 3**	**Average**
12 h	99,42 %	98,49 %	99,65 %	99,2 %
84 h	99,61 %	99,21 %	99,77 %	99,5 %

The results from the AMI meter reading data show that at the 12h mark, 99,2% of the meters have been successfully read and at the 84h mark the rate is 99,5%. This data gives a clear picture of the systems robustness in day to day operations. The AMI-system's ability to deliver a success rate of 99,2% at the 12h mark which is the same as the most lax layer of the multilayered demand response model, shows that the system is quite robust and capable of delivering dependable amounts of demand response in great masses. It was suggested during the interviews that the failure rate of 0,8% could be explained by data connections and issues related to them, such as shadow zones in the metering areas or congestions in the network traffic. (Empower IM Oy, 2014)

It was mentioned in the interviews that the data connections usually do not pose any problems for the system or if there are problems they are in the ballpark of 0,8% as suggested by the robustness data gained from the mass meter reading. At the upper levels of the AMI-system the data connections are more than sufficient and it has been tested that at the maximum the system placing a load of 10% on the performance of the data connections. However, when moving to a lower level, such as the connections between the meters there might be occasional problems with the connections which are caused by unexpected events. (Järvinen, 2014; Komi, 2014; Oksanen, 2014)

The data connectivity solutions are usually built to be on par with the demand in the area, but for example in case of mass events, the additional traffic in the area may overwhelm the data connectivity solutions and cause problems for the AMI-system. The reasoning for this is, that the data connections used by the AMI-system are ranked under the consumer applications such as, voice data communication and usually the 3G and 4G internet connections as well. The reliability of the data connections have a straight effect on the robustness of the AMI-system and in critical demand response related tasks should be prepared for. (Oksanen, 2014)

5.1.3 Analyzing the operational environment

During the interviews it was mentioned that one of the challenges hindering the usage of AMI-systems in demand response related tasks is the current DSO centric operating environment.

Most of the challenges were found to relate straight to the DSOs and to the current electricity market regulation in Finland. The DSOs were described to be hindering utilization of the AMI-systems in demand response related tasks because in DSO centric thinking the operability and performance of the electricity grid comes always first. The way the DSOs think about the operating environment added with tight electricity market regulations directed to the DSOs create an environment where utilization of AMI technology in other tasks than network metering is cumbersome. (Järvinen, 2014; Oksanen, 2014)

The electricity market regulation model directed at the DSOs define a strict path for the DSOs which they may walk. The regulation model describes actions the DSOs may exercise and deviation from this path is greeted by restrictions in profit cuts.

This kind of regulation leads to a challenging situations, as profiting from the AMI-system is not one of the income sources defined in the regulation model. With no compensation in sight, granting access to the AMI-system for other participants seems like extra work with no compensation from the DSO's viewpoint. (Järvinen, 2014; Oksanen, 2014; Partanen & al., 2014)

5.1.4 Summary of the major challenges

In this summary of the previous chapters, it is acknowledged that there exists three major challenges. The first challenge, identified in the part which analyses the control commands, is the variety of different meters, metering systems and upper level systems and the permutation possibilities of these systems. These variations in the AMI-system composition cause slowness in delivering demand response, and make it challenging to participate to the most time critical layers of the multilayered demand response service.

The second challenge, which was identified in the robustness simulation is related to the data connections and especially to the lower level data connections which happen between the smart meters and the low level parts of the meter reading system. The data connectivity issues may not be a major problem in today's demand response applications, but in future, the growing amount of wireless connections may cause problems for the performance of AMI-systems in demand response related tasks.

The last challenge hindering the adoption of demand response services in the current market environment were identified to be the DSOs who own the current AMI-systems. It was also recognized that the problem was not entirely the fault of the DSOs, but also fault of the current electricity market regulation model restricting the actions of the DSOs. This challenge is not a technical challenge as the two other challenges are, but more of a political challenge. The current regulation model can be seen hindering the development and adoption of demand response programs in current market environment.

The next chapter concentrates on proposing solutions to these problems and considers the impacts of these solutions to the future development of the demand response environment.

5.2 Solution proposals for the major challenges

In previous chapter, three major challenges were recognized to be hindering efficient usage of AMI-technology in state-of-the-art demand response service environment. This chapter proposes solutions to the challenges and contemplates on the impacts the solutions have on the demand response environment.

The first solution which tackles the challenge considering the carry-out times of demand response commands in AMI-systems concentrates on system optimization. It was recognized that the current system architecture contains a lot of variability and is in need of simplifying.

The second solution focuses on the challenge related to the telecommunication connectivity solutions. As of yet there are no major problems related to this area, but there is a risk that the connectivity solutions may develop into a major challenge in future. The second solution concentrates on reducing such risks for the future.

The third solution concentrates on the problem related to the regulatory environment which hinders the development and deployment of demand response services in the current market environment.

5.2.1 Optimizing the current AMI-architecture

The varying carry-out times for the demand response commands in the current AMI-systems was one the major problems prohibiting efficient utilization of all the layers in the multilayered demand response service. The problem arises from the need to integrate the various different systems with each other. Each of the integration layers add unnecessary layers to the system which add to the carry-out time and become another system which has to be checked in failure situations. The current AMI-model for carrying out demand response can be seen in Figure 5.4.

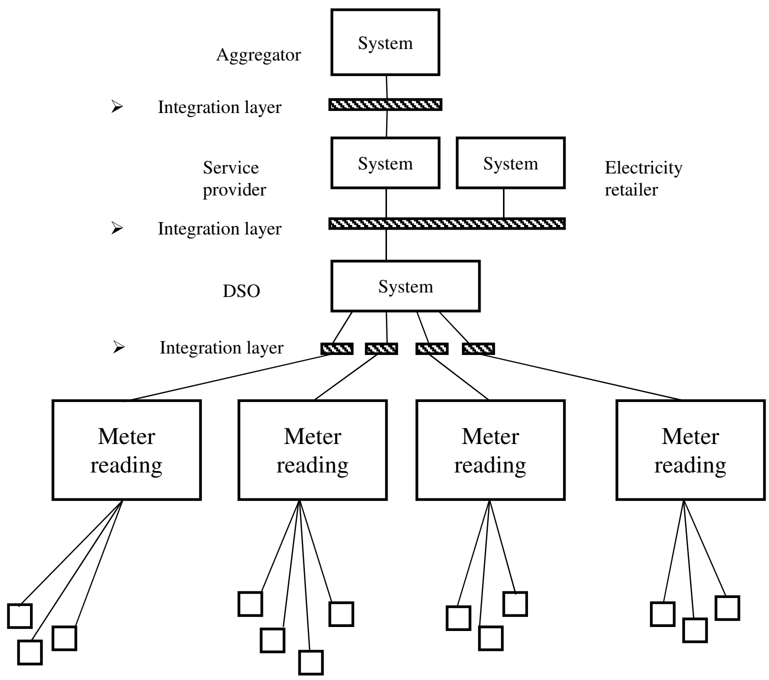

Figure 5.4 Model of current AMI-model for demand response. Model factors in actors such as aggregators and service providers as well.

In the current AMI-model, the upper-level systems (marked as systems in figure 5.4) belonging to different market parties, such as aggregators or electricity retailers have to go through the DSO's systems. This also adds to the carry-out time or causes unnecessary variability in the carry-out times, as the DSO's do not have in place standardized processes for carrying out demand response control commands.

Additionally, the multiple meter reading systems which are not compatible with each other add to the complexity of the system. As pointed out earlier, even within one DSO there may be several systems, which need integration and message translation systems to integrate to the upper level systems.

It is proposed in this solution that the current system will be optimized by simplifying the model and the process which is used for commanding the meters in demand response environment. It is also acknowledged that such task is not as straightforward as it is presented in this thesis, which has led to a proposal where the optimization of the system is done in two stages.

In the first stage, the AMI-system model in itself is not touched. To enable demand response with the current AMI-systems despite the problem with varying carry-out times of demand response commands, it is suggested that a database of the loads behind the meters and the carry-out times is formed. This enables the possibility to utilize demand response in current market environment. By listing the carry-out times for demand response commands and the loads behind the meters, aggregation of the loads becomes easier. An example of the database could be the following, presented in Table 5.3, where consumption site ID is the identification field of a consumption site, carry-out time presents the consumption site specific carry-out time, load size presents the hourly utilizable load size and reliability presents the reliability percentage of demand response actions.

Table 5.3 Example of the information contained in the database, which is used to support demand response aggregation in the early phase of implementation of demand response.

Number	Consumption site ID	Carry-out time	Load size	Reliability
1.	100255	00:00:23	1,12 kWh/h	0,989
2.	100256	00:01:04	2,45 kWh/h	0,78
3.	100257	00:00:38	0,45 kWh/h	0,981
…	…	…	…	…
n	n	nn:nn:nn	n kWh/h	n

In the second stage, the AMI-system in itself is optimized by removing all the unnecessary layers to simplify the process and systems which are used to deliver the demand response commands. The database introduced in the first stage is also utilized on this stage, but this stage concentrates mainly on improving the performance of the system in order to make the most challenging layers of the multilayered demand response service possible.

Compared to the current model presented in Figure 5.4, the new model for delivering demand response through AMI-system introduces a new access layer which handles access to the metering interface and provides a communication gateway between different market participants. This model differs from the current model where the DSO acts as middleman between the AMI-system and the market participants wanting to utilize the controllable loads behind the AMI-meters.

By introducing the new access management layer the DSO will be replaced as the gateway to the AMI-system. Now, all the market participants have similar access to the meter reading system and the quality of service should be similar to every actor. This action in itself does not reduce the system levels between the AMI-system and the market participant, but it does reduce the amount of integration layers between the system levels. The access management layer also integrates the database from the first stage as a Hub-system which handles the actual access rights and load information from the database. The access management layer can be seen in Figure 5.5 below.

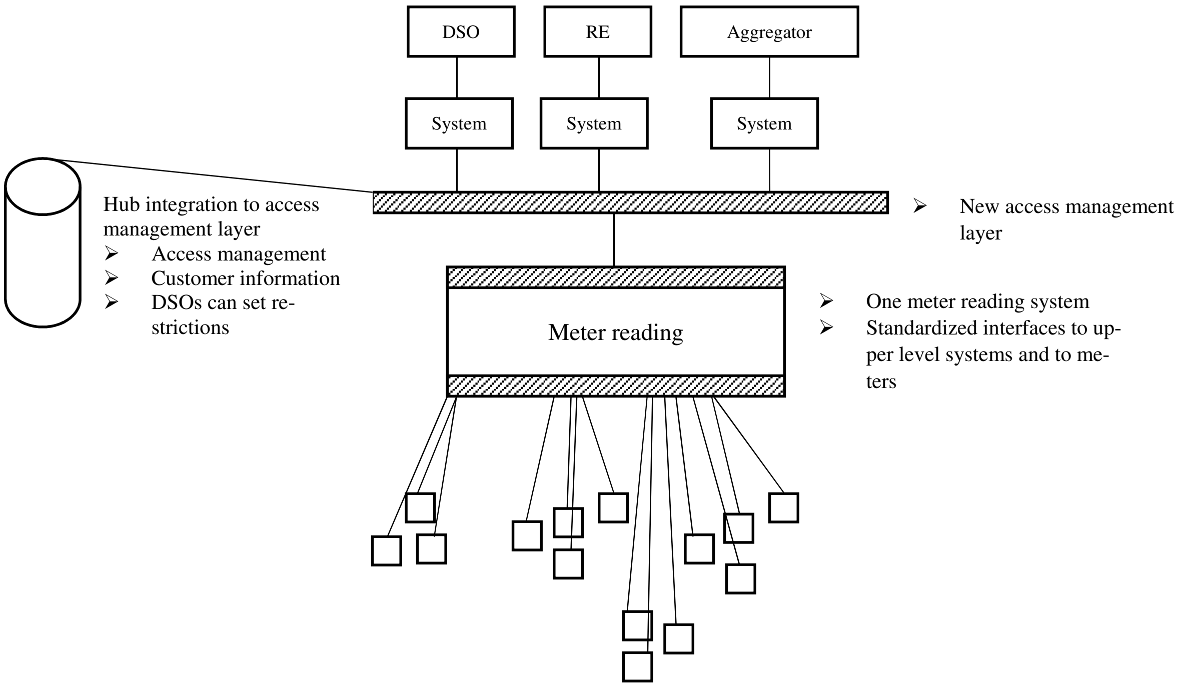

Figure 5.5 New proposed AMI-model for delivering demand response.

Additionally, the new AMI-model for delivering demand response introduces a standardized meter reading and control module. The intention of this change is to reduce the amount of different meter reading solutions on the field and standardize the functions and interfaces needed by the system. While the Figure 5.5 shows only one meter reading system controlling the meters on the lower level, it actually can consist of multiple meter reading systems, but they all have to have the same standardized functions and interfaces to simplify the meter reading domain in the process.

Standardizing and simplifying the meter reading domain makes the devices on the field more homogenous and therefore reduces the variation in the carry-out times for the demand response control commands. This change should provide consistent results for the carry-out times of the demand response commands which are needed for reliable control of the loads behind the smart meters. It has to be acknowledged, that these changes do not make the system significantly faster, but instead, further enhance the robustness of the system.

By giving the standardization treatment for the access layer and the meter reading systems in the AMI-model, it decreases the unnecessary complexity in the system and opens the system for different 3rd party actors by providing easier and cheaper access to the systems and thus increases competition in the demand response environment.

The feasibility of the proposal presented in this chapter has to be contemplated from the viewpoints of the two stages. The first stage which consisted of creating a database full of aggregation assisting information, should be relatively straightforward to implement, as most of the data to be used in the database is already available in the current upper level systems. However, to get consensus of the form of the database, there needs to be industry wide discussions to get input from all the parties related to demand response activities and to gather all the necessities to form a usable database.

The second viewpoint relates to the unifying the system architecture. The unifying of the system architecture relies on the will of the energy regulators and industry actors. The industry actors have expressed a need for unifying the market operations in a recent study, made by Gaia Consulting. In the study, 50 % of the industry actors saw a significant need to standardize the market operations, but at the same time the actors were worried of the high costs related to the development of new IT-systems. (Gaia Consulting, 2012)

One of the thing to remember is that the solution proposed in this chapter is made with the current systems and the current market environment in mind. It is yet unknown how the systems will develop during the next decade. However, it could be said that the most dominant factors related to the development of AMI-systems and demand response services are the future developments in the energy regulation and in the field of data connectivity. Next chapter proposes a solution for future proofing the data connectivity solutions when related to the demand response actions.

5.2.2 Future proofing the data connectivity solutions

The data connectivity solutions play a significant role when looking at the carry-out times and robustness of the AMI-system in a demand response environment. Currently there are many different data connectivity solutions which connect the massive amount of smart meters to the meter reading systems. The variety in connectivity solutions is one of the reasons why demand response carry-out times vary so much, while shadow zones and other signal problems are the other issue which mainly has an impact on the robustness of the AMI-systems.

The variety in the communication methods affecting the current systems is proposed to be averted in the future through standardization of the communication interfaces. As the variety in communication methods is usually connected also to the meter type and age, something would be needed to do to the field devices also. As changing all the field devices to support one standard it is proposed that the change would happen over period of transition. In the transition period newly installed meters would have to adhere to the standardization, while the older meters would be replaced through "natural wastage".

While above presented challenges are the current challenges affecting the system, in future there is one major challenge which has to be taken into account designing telecoms networks. The vast amount of controllable loads participating demand response programs in the future will be needing a network which can deliver performance and be as robust as possible. To give an idea of the amount of connections needed to deliver demand response an aggregator for example needs to aggregate 1000 households with nominal power of 1kWh to deliver 1MW of demand response. To put this into context, the minimum bid for Elspot participation used to be 1MW. Now the minimum bid limit has been lowered to a more demand response friendly 0,1MW.

To avoid possible surprises and failure cases in telecoms networks in the future, when demand response actions become more frequent, the network operators and demand response operators along with DSOs would have to share information between each other on matters such as geographical development, growth of consumption et cetera. Through this communication channel possible congestion situations affecting consumer- and demand response side in telecoms networks could be averted.

5.2.3 Developing the regulation model to support demand response

Last of the major challenges related to the utilization of AMI-systems in demand response environment is the current regulation model and some of the actions of the DSOs. The issue on the hand is not an easy task to solve, as it is not a technical issue and more of a political subject. However, the current regulation model is one the biggest reasons hindering the adoption of demand response in the current market environment.

The current regulation model hinders the adoption of demand response simply because it does not recognize demand response. By not recognizing demand response, the regulation model discourages DSO's from utilizing the full potential of the AMI-systems currently on the field by creating uncertainty among the DSOs. To fully utilize the AMI-systems on the field the DSO's should have incentive to grant access for demand response operations for third party participants, such as aggregators or electricity retailers, or the DSOs should be removed from the picture altogether.

Changes to the regulation model come from the energy politics the government is practicing and influencing the political decision-making does fall out of the scope of this study. However, it is important to highlight the problem, as it is one of the most important factors affecting introduction of demand response for wide audiences in the Finnish electricity market environment.

The regulation model should be changed by including demand response in to the regulation model as a service, which has to be enabled for all market participants and by forming a consensus on how the AMI-systems under the administration of DSOs will be utilized in delivering demand response. There are two possible models for the above-mentioned actions.

In the first model the AMI-systems stays under the DSO's control. The DSO will be responsible for granting access to the AMI-systems and for demand response control commands while observing the usage of the AMI-system. This model would enable the DSOs to earn additional income from the administration of the AMI-system. However, from the viewpoint of demand response, this model reduces the efficiency of the control commands, as standardized practices for operating demand response are not in place. Especially in the case of the multilayered demand response service, the model limits the performance of the service by making the control commands too slow for the most challenging market layers.

In the second model, the AMI-system would be released from the DSO's control and opened for third party market participants. This solution would rely on the AMI-structure previously presented in Figure 5.5. In this model, the DSO would be able to set restrictions beforehand for certain parts of the network, but would not be actively inspecting the traffic. By removing the DSO altogether, this model would assure faster operation for the demand response control commands, which would be essential for services such as the multilayered demand response service. It is recommended that the second model or similar to it would be applied in regulation model development in the future. The recommended model is illustrated in figure 5.6 below.

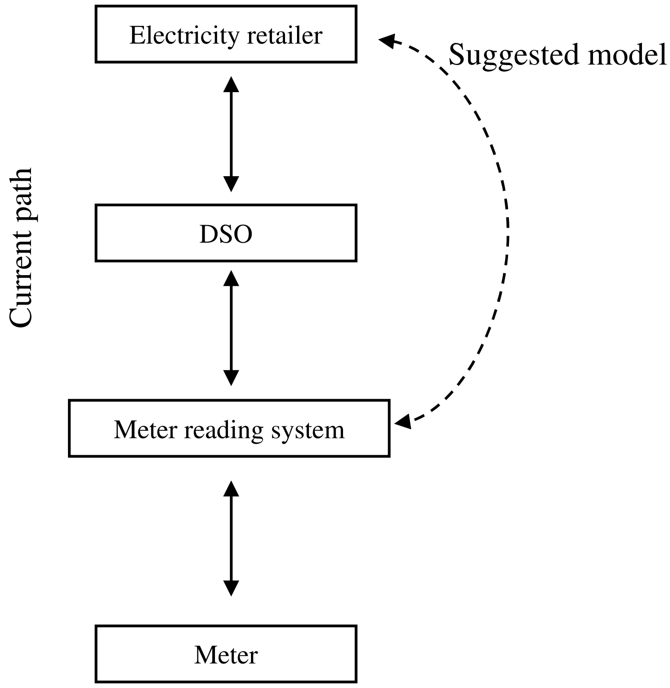

Figure 5.6 Presentation of new regulation model, where DSO is removed from the AMI control command chain. The new communication chain is illustrated by the dashed line.

This chapter concludes the analysis part of the thesis. In the next and final part, of the study conclusions are drawn of the major challenges affecting demand response when paired with AMI-systems. The chapter also ponders on what should be done in the future in the field of demand response and what is needed to enable all the layers of the multilayered demand response model.

6 CONCLUSIONS & SUMMARY

This chapter concludes this thesis by presenting the conclusions and the summary. In the first part of this chapter the conclusions are drawn of the challenges affecting the performance of multilayered demand response service in AMI environment. This chapter also evaluates the effectiveness of the solutions proposed in chapter 5 towards improving the performance of the AMI-systems in multilayered demand response environment. This chapter also gives suggestions on what should be researched in the future and what should be the guidelines for the future development of demand response.

At the end of the chapter a summary is given of the state of demand response and essential research results are presented alongside a table which shows utilization of the multilayered demand response service with the current generation AMI-systems.

6.1 Conclusions

Multilayered demand response service could be enabled in today's systems if the carry-out times from the simulations were to be used as the only criteria. The simulations carried-out in the study showed that the current AMI-systems would be capable of providing demand response to the first four layers of the multilayered demand response service. The layers in question were the layers which had a time requirement between 12 hours to 15 minutes. The remaining layers, which consist of the most demanding power reserves under the Fingrid were still unreachable for the current AMI-systems. However, this was acknowledged when designing the multilayered demand response service and one of the design principles was that when the technology matures and advances, the more challenging layers can be enabled later on.

The simulations which were carried to test the multilayered demand response service, showed that the current AMI-technology was capable of 1 minute 20 second carry-out time. This was an excellent result, but the simulations did not take into account the aggregation which is usually, if not always, needed to deliver sufficient amount of demand response. The addition of aggregation and the needed systems for aggregation would probably increase the carry-out time.

The biggest worries which arose during the simulations were related to the capabilities of the current generation AMI-systems to carry-out demand response commands in the challenging time restraints of the multilayered demand response service and the capability of the AMI-system to send demand response commands in masses to thousands of AMI-meters. For example, the data used for the robustness and mass tests was a bit lacking and the lowest time requirement used for the simulation was 12 hours, which is the slowest time requirement in the multilayered demand response service. However, the data was found to be usable, since it would show that what could be expected from the AMI-systems in the first phase.

The aforementioned simulation tasks, the carry-out time and the mass commands, revealed three major challenges which affect the results negatively. The first challenge was related to the architecture of the AMI-systems. During closer inspection of the AMI-system it was noticed that the systems were very complex. It was also discovered that the DSOs which owned the AMI-systems could have up to five different systems under their command and this naturally creates a need for systems which integrate all these systems together. These various integration layers add to the complexity of the system by adding unnecessary layers to the system which increase the carry-out time of the process and in possible problem situations complicate the problem solving.

To solve the problem, it was suggested in chapter 5.2.1 that the current AMI-system would be substituted with a system, where the meter reading system would be standardized or at least the interfaces to the upper- and lower level systems would be standardized. It was also discovered in the interviews during the study that the meter reading systems, which are in a central role when considering demand response, may not exactly be core competence of the businesses which make the AMI-systems.

Additionally, in the current AMI-architecture model the DSOs act as gatekeepers to the AMI-systems and depending on the DSOs upper level systems and business processes the additional variation to the demand response carry-out times may be significant. Due to this reason in the new AMI-architecture model the DSO as a gatekeeper is replaced with a standardized access management layer which is hoped to remove or at least decrease the amount of variation in the carry-out times of demand response.

Another challenge which was recognized is related directly to controlling the mass of AMI-meters and the telecoms connections used for the controls. The challenge was not directly a technical and therefore there is no technical solution suggested. However, it was suggested in chapter 5.2.2 that in future the actors working with demand response and the actors in the telecoms industry would increase the amount of cooperation to prevent possible issues related to the robustness of the AMI-system under heavy load. This change is important depending on the use case of demand response. For example, if the use case for demand response is system critical, such as, frequency control in distribution networks, the system has to be as robust as possible to deliver the demand response commands which are responsible of the frequency control.

The third major challenge, which was recognized during the study is related to both of the above mentioned challenges. As it was with the second challenge, this challenge is neither related to a technological matter, and is possibly the most challenging of the issues mentioned here. The challenge is related to the current electricity market regulation model, which does not currently make possible to enable demand response through the AMI-systems.

In the last problem solution part, in chapter 5.2.3, it was suggested that the current electricity market regulation model should be reformed. The solution found two possible solutions to the problem. The first solution consisted of reforming the current regulation model so, that it would make it possible for the DSOs to profit from demand response actions. The second solution, which is the more suitable solution from the demand response's point of view, is to bypass the DSO in the AMI action chain altogether, by making it possible for third parties to control the AMI-devices themselves. The latter solution could be achieved by combining the access management layer solution and the latter regulation solution. In this combined solution the DSOs would be provided with a general-purpose interface, which would be used to provide access for electricity retailers to the meter reading system.

Based on estimates provided by Empower IM, the cost of such system would be 4 M€ in total for all DSOs in Finland. The cost structure of the system is presented in table 6.1.

Table 6.1 System cost estimate for general-purpose interface.

System costs			
Component	*Cost [euro/pc.]*	*Amount [pc.]*	*Total*
System as a Service	25 000,00 €	100	2 500 000,00 €
Integration cost	15 000,00 €	100	1 500 000,00 €
		Total	**4 000 000,00 €**

Additionally the implementation of the system would also consist of operational costs, which would be 750 k€ a year for all the DSOs. The rundown of the costs is presented in table 6.2.

Table 6.2 Operational costs estimate for general-purpose interface.

Operational costs	
Component	*Cost [euro/a]*
Maintenance costs	500 000,00 €
Operational costs	250 000,00 €
Total	**750 000,00 €**

If the system- and operational costs were to be summed and then divided between all the consumption site's in Finland, which there were 3 445 000 in 2013 according to Finnish Energy Industries, the installation cost of the system would be 1,16€ per consumption site and the yearly operational costs would be 0,22€ per consumption site. The rundown of these figures is presented in table 6.3. (Energiateollisuus, 2013)

Table 6.3 Estimate of cost per consumption site for system costs and operational costs.

Costs per consumption site			
System cost for all DSOs	4 000 000€	Per consumption site	1,16€
Operational cost for all DSOs	750 000€	Per consumption site	0,22€

As can be seen from the table 6.3, the first year cost of implementing the system summed with the operational cost would be 1,38€ per consumption site per year, if the systems would be paid in the first year. After the first year, the operational costs of the systems would be 0,22€ per consumption site per year. As can be gathered from the results, the costs do not seem that high when divided between all consumption sites, but it should be noted, that the costs presented in the above estimates only take into account control systems. Any additional systems or changes to these systems are not included in these cost-estimates.

Some of these solutions to the problems presented are very difficult to realize, such as the creation of a standardized meter reading system or interface, whereas changing the regulation model so that the DSOs could profit from the AMI-systems look straightforward from engineering point of view. In reality opening the command interface to 3rd parties, might bring a whole slew of new problems, which have not been considered in this thesis. For example, how are the control commands supervised that there is no harm to be done for the electrical grid via the commands? Or is it even possible to send control commands in masses with all meter reading systems? It also should be acknowledged, that the suggested solutions do not take into account the continuing development of the AMI-systems and the possible forthcoming of HEMS-systems, where each of these advancement would render the suggested solutions fruitless.

However, at the moment, the DSOs and other electricity market participants are eager to exploit the newly installed AMI-systems and as the systems are still new, procurement of new systems is highly unlikely. Therefore, the suggested solutions could be worthy alternatives to enable the current AMI-systems in delivering demand response and to make a basis for future development of the systems, if all possible new challenges have been addressed.

6.2 Future research

This thesis consisted of analyzing the performance of current generation AMI-systems in a state-of-the-art demand response environment. Most of the study focused on the carry-out times of demand response commands, which are critical for the performance of demand response, but the study left out several interesting topics, which should be researched before continuing the work presented in this study.

The first topic is related to aggregation. The study grasped aggregation briefly in the theory part and as a part of the regulation model reform chapter, but there is still many matters to solve in the aggregation segment. One of the major things related to aggregation and this study, is investigating the time requirement for aggregation in massive demand response applications. By studying aggregation and the time required for aggregation, it is possible to define the true carry-out time for demand response.

Second topic is how the multilayered demand response service model would affect the market layers described in chapter 4.1.1. The most interesting part would be the Fingrid operated power reserves, as the volume of capacity is not as big as in the Elspot or Elbas markets. Future research should study how the demand response affects the market prices and the share of other resources offered to these markets, as demand response would probably be the cheapest option to provide the resources, when compared to traditional gas turbines.

Third topic to be researched should concentrate on comparing the features and characteristics of the meter reading systems, as there are as many different meter reading systems as there is companies developing these systems. This thesis concentrated on only one system and it is not clearly enough to signify that all the systems would be capable of delivering demand response in masses.

Future research should also take a look at the multilayered demand response model. As it is, the model consists of 7 different layers, as there were 7 identified markets available in the Nordic electricity market. The study however does not take a stand on if all the 7 market layers are needed.

Last research topic would be the demand response itself. Studying demand response should focus on the amount of demand response and what kind of impact it can provide in the current applications. For example, what are the volumes of demand response needed to be aggregated to deliver a sufficient amount of demand response resources to current applications?

6.3 Summary

Finland has nearly a 100% penetration rate in smart meters since the start of 2014. The companies operating these meters have started to look for other use cases for these meters than the remote meter reading already enabled with these devices. One possibility could be the utilization of these meters in delivering active demand response as a service for various electricity market participants, such as electricity retailers or aggregators.

Electricity retail companies might be interested of active demand response as an active balance management tool for their electricity procurement activities. Also the growing amount of RES increase the variability in electricity generation which causes more challenges to electricity retail companies. To answer this need a multilayered demand response service was designed. The service would consist of 7 different market layers which the user of the service could utilize for active imbalance management.

The study then compares how the current generation AMI-systems would cope in a state-of-the-art demand response environment. The main objective was to find out how well the current generation systems could utilize the multilayered demand response environment and what would be the bottlenecks restricting the systems fully utilizing the service. It was found out that the current generation systems would be able to reach demand response command carry-out times of 1 minute 20 seconds, when not including aggregation. It was also found out that in mass simulations the current systems could deliver around 98% of the commands in 12 hours. Due to the lack of simulation data, testing behavior of the mass was not possible with stricter time requirements.

It was found during the simulations that there were three major challenges hindering the adoption of demand response on a wide scale. The challenges were the current AMI-system architecture, data connectivity solutions and the current regulation model. Three solutions were proposed to address these problems. While the solution regarding the AMI-system architecture was probably the most complex and least realizable, the solutions regarding data connections and regulation model were a bit more straightforward from an engineering point of view. Though, a foreword of the latter two challenges, they are somewhat political and therefore may not be as easy to solve as it seems.

Overall despite the challenges it was found out, that the current generation of AMI-systems could reach at least 4 first layers of the 7 layer demand response model. Most of the challenges related to these first layers are related to regulation and data connectivity. The challenges which prohibit the AMI-system from reaching the 3 next layers are related to the carry-out times of demand response commands and different market restrictions, such as the type of the resource. Also, some of the layers of the multilayered demand response service have quite challenging requirements for the amount of power to be delivered, such as 10 MW which could be challenging to provide through demand response. Summary of the results of the study is presented in table 6.4 and in table 6.5. Table 6.1 presents the results related to the Nord Pool Spot operated markets, whereas table 6.2 present the result related to the Fingrid operated markets.

Table 6.4 Summary of the Nord Pool Spot operated markets.

Product	**Descrip-tion**	**Require-ment**	**DR reach from time perspective**	**Challenges**	**Present sit-uation**	**Future needs**
Elspot	Nord Pool Spot oper-ated day-ahead mar-ket	12h and 0,1MW	100 %	Should be possible, if data con-nections do not restrict usage	100% of DR could be utilized with Elspot	Regulation model Standardi-zation. Oth-erwise could be reachable.
Elbas	Nord Pool Spot oper-ated hourly market	1h and 0,1MW	98 %	Should be possible, if data con-nections do not restrict usage	98% of DR could be utilized. Could be considered as reachable layer.	Above mentioned challenges apply. Oth-erwise could be reachable.

Table 6.5 Summary of the Fingrid operated markets.

Product	**Descrip-tion**	**Require-ment**	**DR reach from time perspective**	**Challenges**	**Present sit-uation**	**Future needs**
Regulation market	Fingrid op-erated regu-lation power mar-ket	45 min & 10MW	98 %	Should be possible, if data con-nections do not restrict usage	98 % of DR could be utilized. Could be considered as reachable layer.	Regulation model Standardi-zation. Oth-erwise could be reachable.
FRR-M	Fingrid op-erated man-ual fre-quency res-toration re-serve	15 min & 10MW	97 %	Should be possible, if data con-nections do not restrict usage	97 % of DR could be utilized. Could be considered as reachable layer.	Above mentioned challenges apply. Oth-erwise could be reachable.
FCR-N	Fingrid op-erated nor-mal fre-quency con-tamination reserve	3 min & 0,1MW	93 %	Challenging timeframe. Depends on the speed of aggrega-tion.	Maybe reachable with current systems. Time con-straints are challenging.	Faster de-mand re-sponse pro-cess. Above presented challenges apply.
FRR-A	Fingrid op-erated auto-matic fre-quency res-toration re-serve	2 min & 5MW	90 %	Challenging timeframe and does not accept current forms of DR as re-sources	Maybe reachable with current systems. Does not accept DR resources.	Changes to the allowed load control resources. Currently only hydro and heat.
FCR-D	Fingrid op-erated dis-turbance frequency contain-ment re-serve	instant - 30 sec & 1MW	3 %	Current AMI-systems are not capable of deliver-ing demand response in target time.	Not reacha-ble. Would be ideal for DR.	Loads be-hind AMI-meters would be ideal, need faster acti-vation.

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Interviews:

Arto Järvinen, Service Manager	8.4.2014, Hämeenlinna
Mikko Gröhn, Leading Expert	24.4.2014, Email
Antti Oksanen, Service Manager	28.8.2014, Helsinki
Maiju Komi, System Specialist	1.9.2014, Email & Lync

USE CASE DESCRIPTION

1 GENERAL INFORMATION

Use case number	ICARE UC # (To be defined later)
Use case name	[Please insert a self-explanatory name for the use case]
Author/partner	[Author's name and organization]
Summary	[Please summarize the main goal of the use case. Describe what can be achieved by executing this use case]
Rationale	[Please describe the problem that the use case solves, and the importance and significance of the use case in the viewpoint of the whole system]

1.1 Use case description

[Please enter a free form description of the use case. Pictures are also welcomed to illustrate the use case]

2 CONTEXTUAL SETTINGS

2.1 Context description

[Please enter a free form description of the context of the use case. Pictures or context diagrams are also welcomed to assist the understanding of the use case context]

2.2 Actors

[Please identify the actors interacting with the system during the use case execution (e.g. human actors with different roles, other services and systems). For each actor, describe his/hers/its responsibilities in the use case execution]

Actor name	Actor responsibilities

2.3 security

[Please identify the security issues and explain what should be protected]

2.4 resources

[Please envision the infrastructure, physical resources and software artefacts needed for the use case execution]

2.5 Frequency of use

[Please estimate the time frame and how often this use case will be executed (e.g. values such as 100 times per hour)]

3 FUNCTIONAL DESCRIPTION

[Please describe the functional characteristics of the use case according to following table]

Preconditions and assumptions	[Describe any preconditions and assumptions that must be true and valid when executing the use case]
Trigger	[Identify the event that initiates the use case]
Normal flow	[Enter the description of the normal flow of the successful execution of the use case]
Alternative flow (optional)	[Enter the description of an alternative flow, if any, of the successful execution of the use case]
Post-conditions	[Describe the state of the system after the use case has been used successfully]

4 NON-FUNCTIONAL DESCRIPTION

[Please describe the following quality viewpoint for the use case, if applicable. Consider all the elements of the use case, i.e. actors, the use case function, actor-use case relations and the use case environment]

Reliability	[Describe the characteristic required for failure free operation of the use case (e.g. failure prevention, detection and recovery considering data reliability, communication reliability, use case function reliability and environment reliability)]
Availability	[Describe how to ensure that the use case function is ready for use when required]
Performance	[Describe characteristics that enable the use case to process a request in a reasonable time]
Security	[Describe the how the unauthenticated use of the use case is prevented]
Interoperability	[Describe how the information sharing and co-operation with the rest of the system is enabled]
Adaptability	[Describe how the use case can be adapted to changes]
Variability	[Describe how the functionality of the use case can be varied to different situations]
Scalability	[Describe how the size or volume of the use case can be scaled in order to meet user needs]
Personalization	[Describe how the use case enables personalization according to single user's preferences]

5 BUSINESS PROPERTIES

[Please describe the following attributes from the viewpoint of the functionality presented in the use case]

Customer segment	[Describe who are the customers targeted in the use case]
Value proposition	[Describe what kind of additional value is built for the customers in the use case and which customer's needs the use case fulfils]
Channels	[Describe which channels are used for distribution, sales and communication in the use case]
Customer relationship	[Describe what kind of customer relationships can be identified from the use case and how they are established and maintained]
Revenue streams	[Describe what kind of revenue streams can possibly resulting from the use case]
Key Resources	[Describe the key resources and assets in the use case]
Key Activities	[Describe the key activities of the use case]
Key Partnerships	[Describe what kind of partnerships could be formed in the use case]
Cost Structure	[Describe from what are the costs consisting of in the use case]

6 CONSTRAINTS

[Please identify constraints that may restrict the operations of an actor, execution of the use case or the interactions between actors and the use case, or are associated with the use case environment]

Location	[Describe constraints for the location of the use case to execute]
Environmental characteristics	[Describe environmental settings outside the use case that should be taken into account (e.g. other actors in the environment or environmental attributes)]
Domain	[Describe the major domain concepts and their relationships that constrain or influence the use case. Identify domain regulations and customs that should be taken into account. Identify also domain ontologies, if any, that are intended to use]
Legislation and standards	[Identify the dominant laws that restrict the use case. Identify also common standards that should be followed / taken into account. Describe their influence to the use case]
Organisation	[Describe organisational rules, policies and customs that should be considered in the case of the use case]
Other?	[Describe any other identified or emerged constraints for the use case]

7 ACTOR LINKS

[Describe any relation, from actor B to actor A, identified for the use case. Please not that to describe a bidirectional link, you will just need to describe twice the relation inside the table]

8 DATA DESCRIPTION

[Please describe any data used in this use case as the frequency delivery, the security issues, the delivery precision in time and in measurement, and etc. Please not that for any actor link described in 7, there is at least one data associated].

Name	**[Data model]**
Content	[Describe the content of the Data model]
Location/Relation	[Describe the location or the actor relations where this data model will be used]

Appendix B

Description	[Describe precisely the data flow and its uses]

Name	**[Data model]**
Content	[Describe the content of the Data model]
Location/Relation	[Describe the location or the actor relations where this data model will be used]
Description	[Describe precisely the data flow and its uses]
…	…

9 THREATS AND EXCEPTIONS

9.1 Misuse cases

[Please describe any threats that can be identified for the success of this use case. For example, identify malign/hostile actors (e.g. system abusers, hackers or viruses) and misuse cases, and describe how the use case is to respond to those threats]

9.2 Exceptions

[Please identify any anticipated exceptions and error conditions that could occur during execution of the use case, and describe how the use case is to respond to those conditions. Also describe or estimate the state of the system after the use case has not met its main goal]

10 OTHER RELEVANT INFORMATION

[Please provide here any other relevant information, if any, that is not included in the other sections of this template

USE CASE DESCRIPTION

1 GENERAL INFORMATION

Use case number	SEAS UC #64
Use case name	Demand flexibility service for day-ahead electricity market (Elspot)
Author/partner	Olli Huotari, Empower IM Oy
Summary	Through this use case electricity retailer can limit exposure to imbalance risk by utilizing demand response and also has the possibility to get more accurate electricity consumption forecasts for the day-ahead market.
Rationale	Imbalance in electricity generation and consumption causes the electricity retailers to cover this imbalance through trading in intra-day and regulation power markets which can cause higher electricity prices for end-users.

1.1 Use case description

Electricity retailers procure most of their electricity through the day-ahead electricity market. This means that the retailers have to forecast their electricity consumption for the next day as accurately as possible in order to procure just the right amount of electricity. If electricity retailers fail to forecast their electricity consumption as accurately as possible, they risk to exposing themselves to the imbalance power risk.

To achieve more accurate consumption forecasts the retailers could utilize the most recent historical consumption data collected by the AMR/HEMS-systems. This data could be used as the basis of the consumption forecast. Additionally the consumption forecast could also be weather corrected by using the most current weather data.

Now, having the most accurate electricity consumption forecast the retailers can make their procurement bids with less uncertainty and with limited imbalance risk exposure. This should lead to lower electricity procurement costs which could translate to lower electricity prices for the end-users.

Another usage for the use case is gathering information about possible demand flexibility resources, which can be pooled together for usage on next day.

2 CONTEXTUAL SETTINGS

2.1 Context description

This use case is linked to the electricity market context and more accurately to electricity procurement done by the electricity retailers. In Finland electricity retailers procure 70% of their electricity need through the day-ahead market. This demands careful and accurate estimates of their electricity consumption in order to secure just the right amount of electricity for the next day.

However, usually there is some inaccuracy in these estimates and this exposes the electricity retailers to imbalance risk. Exposure to the imbalance risk means that the electricity retailers have to fill the gaps in their procurement plan by buying more expensive balancing/regulation electricity from either the intra-day electricity market or the regulation power market.

2.2 Actors

Actor name	Actor responsibilities
Electricity retailer	- Forming electricity consumption forecast - Making bids according the forecast to the day-ahead electricity market
Weather forecaster	Delivering the most recent and most accurate weather forecast near each consumption site
AMR / HEMS system	- Collecting hourly usage data of the end user - Reporting availability of possible demand response resources - Activating demand response resources
End user	Accepting possible demand response actions defined by the electricity retailer and AMR / HEMS system

2.3 security

- End user data, mainly the user-specific hourly metered consumption data
- Information exchange hub security
- Secure data communication channels to prevent "eavesdropping"

2.4 resources

- AMR/AMI systems in place for data acquisition
    - Option #2 HEMS systems in place
- Sufficient data network capacity for moving large amounts of data
- Sufficient back-end systems for forming consumption forecasts
- Electricity market information
- Information exchange hub

- retailer forecasting tools

2.5 Frequency of use

The use case will be executed once per every day, before the gate closure time for day-ahead bids.

3 FUNCTIONAL DESCRIPTION

Preconditions and assumptions	[Describe any preconditions and assumptions that must be true and valid when executing the use case] - Historical electricity consumption data o load curves - Data of available/possible demand response resources - Electricity market data hub - AMR/(HEMS)-system
Trigger	[Identify the event that initiates the use case] Electricity retailer has to make purchasing bids to day-ahead electricity market.

Normal flow	[Enter the description of the normal flow of the successful execution of the use case]
	Case #1 – Distributed computing
	1. When joining into an aggregated demand response service, the end user will disclose all the electrical loads (technical data) and how the loads can be controlled (economic conditions) in the contract between himself and the service provider
	    1. The technical aspect of load control will be handled by the HEMS
	    2. Economic aspect of demand response will be handled by the retailer or a third party market member (e.g. the contract has following values: load size 1,8kW, max load switch-off 30min, max number of switch-offs: 3, minimum time between switch-offs 180min)
	2. Retailer sends a request for a consumption forecast to the consumption site through his IT-systems **or** the HEMS will automatically update the next day's consumption forecast to the retailers IT-systems.
	    1. The AMR/HEMS system at the consumption site receives the request, checks the next day's consumption forecast based on historical data and forms the consumption forecast for the next day
	3. If the retailer notices that there is a need to limit the next day's consumption, the retailer check the availability of commercially available demand response and if need be, sends the HEMS-system a consumption restrain sequence for the next day.

	4. The AMR/HEMS system receives the consumption restrain sequence and sends updated consumption forecast to the retailer based on the consumption restrain sequence. 5. Retailer checks out the consumption forecast. 6. Retailer forms his electricity procurement plan 7. If need be, the retailer reserves demand response resources for the next day (such as energy storages, think EVs and HVACs) and confirms the performing of the consumption restrain sequence at the consumption site the next day. 8. Retailer forms Elspot offer for the next day 9. On the next day, the HEMS validates the observed consumption at the consumption site and reports back to the retailer. If need be the HEMS system reports locally to the end user about the consumption restrain sequence.
Alternative flow (optional)	[Enter the description of an alternative flow, if any, of the successful execution of the use case] Case #2 – Centralized computing 1. Retailer logs onto the electricity market data hub and checks the historical consumption data and availability of demand response resources under his portfolio 2. Retailer form electricity procurement plan for the next day 3. Retailer validates demand response availability and sends the run orders to each resource 4. The resources acknowledges receipt of demand response commands and commits to perform 5. Retailer receives amounts of committed resources 6. Retailer updates his electricity procurement plan 7. Retailer submits his electricity procurement bids accordingly
Post-conditions	[Describe the state of the system after the use case has been used successfully] Retailer has successfully formed electricity procurement forecast for the next day and acquired demand response to balance his electricity procurement costs. The use site gets rewarded accordingly.

4 NON-FUNCTIONAL DESCRIPTION

Reliabil-ity	[Describe the characteristic required for failure free operation of the use case (e.g. failure prevention, detection and recovery considering data reliability, communication reliability, use case function reliability and environment reliability)] 1. The HEMS or AMR unit has to be able to collect electricity usage data locally and store it safely to: a. local data bank b. retailers/aggregators data bank 2. If the most recent data is unavailable the system has to have a backup system which can be accessed in order to be able to utilize the most recent historical data 3. The data connectivity solutions have to be sufficient to be able to handle massive amounts of data moving between the consumption site and the central computing platform 4. The energy data management and the energy management systems which read the meters and create consumption forecasts have to have backup systems. Although, most of these system are very robust and reliable.
Availabil-ity	[Describe how to ensure that the use case function is ready for use when required] The use case availability has a few limitations. The most important limitation the use case has is the gate-closure time of the electricity market. In case of the Elspot market the gate-closure time is 12:00 CET. This is the primary deadline for the use case run time. Another limitation the use case might experience is the limited accessibility to the AMR unit caused by unreliable data connectivity. Certain actions, such as meter reading or pushing control messages, might cause some strain on the meter reading system, which may time to time lead to unavailability. The above mentioned limitations can be scheduled so that they do not affect the availability of the use case for the market participants.
Perfor-mance	[Describe characteristics that enable the use case to process a request in a reasonable time] Elspot market place is a day-ahead market which means that the bids have to be submitted only once a day and 12 hours before the delivery hour. This means that the systems associated with the use case have reasonable amount of time to act to the command prompts sent by the users of the use case.

Security	[Describe the how the unauthenticated use of the use case is prevented] The systems needed to read and control the demand response resources can only be accessed through a secure VPN-connection, which is configured to match only the use case user's machine.
Interoperability	[Describe how the information sharing and co-operation with the rest of the system is enabled] The energy management system operated by the use case operator shares the data to necessary partners by using standardized market messages. It would be ideal if the interfaces between different systems would be standardized, but the energy management system also has the ability to translate different message types into standardized formats if there is a need to do so.
Adaptability	[Describe how the use case can be adapted to changes] Due to the flexible nature of the energy management system the use case becomes modular. The energy management system can connect to different types of AMR/HEMS-units, it can connect to different markets and so on. For example, if the AMR-system used to read the measurement data turns out to be too slow for certain markets the system can be replaced easily from the perspective of the energy management system.
Variability	[Describe how the functionality of the use case can be varied to different situations] The use case is designed in such way that it can be adapted to different markets when, for example, certain technological solutions become available. In case of the Elbas market there is a need for faster data collecting and processing than the Elspot market due to stricter market rules. The system can adjust itself to become compatible with Elbas by changing the meter reading system.
Scalability	[Describe how the size or volume of the use case can be scaled in order to meet user needs] Due to its modular structure the use case is able to scale to different situations.
Personalization	[Describe how the use case enables personalization according to single user's preferences] The use cases uses each end user's personal electricity consumption data. This data can be used to make user profiles for every end user to experience more personal.

5 BUSINESS PROPERTIES

Customer segment	[Describe who are the customers targeted in the use case] - Prosumers - Consumers - Industry - SMEs - DSOs - TSOs - Municipalities - OEMs
Value proposition	[Describe what kind of additional value is built for the customers in the use case and which customer's needs the use case fulfils] The value propositions of the use case can be divided into three categories. Each of the categories contain a set of different value propositions. The value propositions in whole are listed below: - Green value proposition o Less emissions o Better fuel efficiency o Better use of natural resources - Efficiency value proposition o Optimum network management o Efficient peak load management o Optimum use of available resources - Business value proposition o Achieve monetary savings o Achieve better value for the money o Gain more customers o Imbalance risk management
Channels	[Describe which channels are used for distribution, sales and communication in the use case] - Mass marketing for raising awareness - Targeted marketing to large customers - Marketing at seminars aimed to the electricity market participants

Customer relationship	[Describe what kind of customer relationships can be identified from the use case and how they are established and maintained] - Self-service portal - Personal account management - Co-creation of retail production with prosumers
Revenue streams	[Describe what kind of revenue streams can possibly resulting from the use case] - Flexibility payments from the flexibility market €/MWh (Peak load management, imbalance risk management) - Cost savings due to lower market price €/MWh (Anticipated day-ahead price subtracted with the actual day-ahead price) - Cost savings due to lower emission costs (savings from emission trading) - Service payments €/MP/month - Production payments €/MWh (production from the prosumers) - Network investment savings €/a (savings achieved due to less investments to network) - Peak power capacity generation savings (no need to build expensive peak power units)
Key Resources	[Describe the key resources and assets in the use case] - Flexible loads - Flexible production - Information exchange - Energy management system - Measurement data management system - Data collection system - Control system - Day-ahead market - Flexible market instruments - market based balance management - Portfolio management system (money) - Load / production forecasts - measured values for established load / production

	- Market offering - Market prices - Trade levels based on market prices - measurement and confirmation of flexibility acts carried out - Emission forecasts - Emission markets - Emission measurements
Key Activities	[Describe the key activities of the use case] - Collecting measurement data - Load / production forecasts - Load control - Production control - Network control - Network availability management (in case the network is weak) - Resource availability management - Cost / benefit management - Market trading - Verifying actual flexibility amounts (this has to be done against an agreed reference base line)
Key Partnerships	[Describe what kind of partnerships could be formed in the use case] - DSO (metering) - TSO (metering) - Marketplace - OEMs - System vendors - Prosumers - Consumers - Producers - Balance responsible parties (BRP)
Cost Structure	[Describe from what are the costs consisting of in the use case] - Balance electricity €/MWh

	- Spot electricity €/MWh - Measurement data €/MP/a - Control actions €/MP/action - Information exchange costs €/MP - Lost revenue due to load flexibility €/MWh - Market membership cost €/a - Flexibility cost €/MWh - Energy cost €/MWh - Emission payments - various TSO fees €/MWh

6 CONSTRAINTS

Location	[Describe constraints for the location of the use case to execute] The use case is designed for the Elspot. This in itself constrains the use case to countries which use Nord Pool Spot to trade electricity. (Denmark, Finland, Norway, Sweden, Estonia, Latvia and Lithuania)
Environmental characteristics	[Describe environmental settings outside the use case that should be taken into account (e.g. other actors in the environment or environmental attributes)] The most biggest environmental forces that may constrain the use of the use case are: 1. Electricity market changes 2. Energy policy changes
Domain	[Describe the major domain concepts and their relationships that constrain or influence the use case. Identify domain regulations and customs that should be taken into account. Identify also domain ontologies, if any, that are intended to use]
Legislation and standards	[Identify the dominant laws that restrict the use case. Identify also common standards that should be followed / taken into account. Describe their influence to the use case] - Electricity market law - Finnish energy policy
Organisation	[Describe organisational rules, policies and customs that should be considered in the case of the use case]
Other?	[Describe any other identified or emerged constraints for the use case]

7 ACTOR LINKS

[Describe any relation, from actor B to actor A, identified for the use case. Please not that to describe a bidirectional link, you will just need to describe twice the relation inside the table]

8 DATA DESCRIPTION

[Please describe any data used in this use case as the frequency delivery, the security issues, the delivery precision in time and in measurement, and etc. Please not that for any actor link described in 7, there is at least one data associated].

Name	**Retailer request**
Content	Request for decision making support data
Location/Relation	Retailer – Weather forecaster Retailer – HEMS Retailer – Aggregator Retailer – DataHub
Description	Requests data from the sources listed above to support decision making in case of imbalance management and demand response activation. Data consists of weather data, demand response resource statuses etc.

Name	**Retailer command**
Content	Demand response control commands
Location/Relation	Retailer – Aggregator Retailer - HEMS
Description	Control commands for demand response resources. Depending on the aggregation model the control commands will be sent either to aggregator or directly to the HEMS system.

Name	**Aggregator request**
Content	Request for decision making support data
Location/Relation	Aggregator – HEMS Aggregator – Weather forecaster Aggregator – DataHub
Description	Requests data from the sources listed above to support decision making in case of imbalance management and demand

	response activation. Data consists of weather data, demand response resource statuses etc.

Name	**Aggregator relay**
Content	Report data
Location/Rela-tion	Aggregator - Retailer
Description	Report data of the load control commands to the retailer. Consists of amount of demand response, activation times, etc.

Name	**Aggregator command**
Content	Demand response control commands
Location/Rela-tion	Aggregator - HEMS
Description	Control commands for demand response resources. Sent to the HEMS systems. Consist of activation times, run times and demand response amounts.

Name	**Weather forecaster relay**
Content	Weather forecast data
Location/Rela-tion	Weather forecaster – Retailer Weather forecaster – Aggregator
Description	Weather forecast data related to the consumption sites listed in the data sent by the aggregator or retailer. Depending on the aggregation model, the data will be sent to the party which is doing the aggregation of loads.

Name	**AMR/HEMS system relay**
Content	Consumption data and demand response resource data
Location/Rela-tion	HEMS – Retailer HEMS - Aggregator

Description	Data flows from HEMS to retailer or aggregator, depending on the aggregation model. The data is used to form the demand response control commands at the retailers/aggregators end.

Name	**AMR/HEMS system command**
Content	Control command
Location/Relation	HEMS – resources connected to the HEMS
Description	Data flow goes from the HEMS to the resources and systems under the command of HEMS. The commands are used to control the systems.

Name	**DataHub relay**
Content	Supportive data
Location/Relation	DataHub – Retailer DataHub - Aggregator
Description	DataHub relays supportive data upon request to retailer or aggregator.

Name	**End user command**
Content	Control command, information input
Location/Relation	End-user - HEMS
Description	End-user can control the amount of demand response resources available to the HEMS system.

9 THREATS AND EXCEPTIONS

9.1 Misuse cases

This use case is able to control the level of electricity consumption and production in the electricity grid and could be potential target for different hostile groups.

Even though the use case is not connected to the public internet, there always lies a possibility that someone hacks into the system. The system needs to be implemented with safety limits which are able to prevent any system wide harm.

9.2 Exceptions-

10 OTHER RELEVANT INFORMATION

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