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MATTI ARO

DEMAND RESPONSE POTENTIAL OF AGGREGATED LOADS IN INDUSTRIAL ENVIRONMENT

Master of Science Thesis

Examiner: Professor Pertti Järventausta
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ABSTRACT

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In the power system, electricity production and consumption must be constantly balanced. Without balance, the frequency of the power system deviates from its rated value and that may result in device failures and large-scale power outages. In the Nordic area, power grids of Finland, Sweden, Norway and East Denmark are synchronously connected, which means that the grid frequency in these areas is the same at all times. In Finland, the power balance is maintained by Finnish Transmission System Operator, Fingrid, by managing the power reserve market which aim to ensure the power balance also in the cases of disturbances.

In order to maintain the power balance, the production and consumption of electricity must continuously be regulated. Traditionally, the balance has been maintained by regulating the production side. As renewable, weather-dependent power generation, such as solar and wind power, has become more in common, the production side is losing its controllability. The demand side has to engage in the balancing more heavily than before. Demand Response means controlling consumption, for example, on the basis of electricity price signal. Shifting consumption from times of high electricity prices to lower ones helps also the power system because high electricity price is a sign of electricity shortage.

The aim of this thesis was to find out the Demand Response potential of Rauma paper mill, which is part of a Finnish forest industry company UPM. The aim was also to develop a generalized method for identifying flexible loads in an industrial environment and an analysis tool to guide them to the most profitable DR markets. The DR potential mapping was carried out in stages, of which the most important were: collecting the data of all motors in area, defining the most crucial boundary conditions and finding motors that meet them, and analyzing the found potential.

Based on this study, the paper industry in general holds a significant potential to participate in DR markets. Some of this potential could be utilized in the DR market almost without any investment. At least this potential should be harnessed to produce additional value.

TIIVISTELMÄ

Matti Aro: Aggregoitujen kuormien kysyntäjoustopotentiaali teollisessa ympäristössä
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Avainsanat: kysyntäjousto, sähkömarkkinat, tehotasapaino, tehoreservi

Sähkövoimajärjestelmässä sähkön tuotannon ja kulutuksen on oltava jatkuvasti tasapainossa. Ilman tätä tasapainoa taajuus poikkeaa sille asetetusta nimellisarvosta, joka voi johtaa laitevaurioihin sekä laajamittaisiin sähkökatkoihin. Pohjoismaissa sähköverkot on kytketty synkronisesti yhteen Suomen, Ruotsin, Norjan ja Itä-Tanskan osalta, mikä tarkoittaa, että taajuus näiden alueiden sähköverkoissa on koko ajan sama. Suomen osalta sähköverkon tehotasapainosta huolehtii Suomen kantaverkkoyhtiö Fingrid, joka ylläpitää säätösähkö- ja reservimarkkinoita, joilla pyritään varmistamaan tasapaino myös häiriötilanteissa.

Tehotasapainon ylläpitämiseksi tuotantoa ja kulutusta täytyy jatkuvasti säätää ja perinteisesti tasapainoa on ylläpidetty tuotantopuolta säätämällä. Uusiutuvan, sääolosuhteista riippuvaisen sähköntuotannon, kuten aurinko- ja tuulivoiman yleistyessä kulutuksen täytyy enenevissä määrin osallistua tehotasapainon hallintaan. Kysyntäjoustolla tarkoitetaan kulutuspuolen kuormien ohjaamista esimerkiksi hintasignaalin perusteella halvemman sähkön ajalle, jolloin tarjontaa on kysyntään nähden hyvin saatavilla.

Tämän diplomityön tarkoituksena oli selvittää suomalaisen metsäteollisuusyhtiö UPM:n Rauman paperitehtaan sähkön kysyntäjoustopotentiaali sekä ohjata mahdollisesti löytyvä potentiaali kaikkein kannattavimmille säätösähkö- tai reservimarkkinoille. Lisäksi tässä työssä oli tarkoituksena kehittää yleispätevä metodi joustavien kuormien tunnistamiseen teollisessa ympäristössä, jota voitaisiin hyödyntää muiden samankaltaisten tehtaiden potentiaalin kartoittamiseen. Kysyntäjoustopotentiaalin kartoittaminen suoritettiin vaiheissa, joista tärkeimmät olivat: tarkasteltavan alueen moottorilistojen kerääminen, tärkeimpien reunaehtojen määritteleminen, moottorilistan läpikäyminen ja sieltä reunaehdot täyttävien moottoreiden tunnistaminen, joustavan kapasiteetin käytettävyyden määrittäminen, sekä joustavan potentiaalin ohjaaminen taloudellisesti kannattavimmalle markkinalle.

Tämän tutkimuksen perusteella voidaan paperiteollisuudella todeta olevan huomattava määrä potentiaalia osallistua kysyntäjoustomarkkinoille. Osa tästä potentiaalista voitaisiin hyödyntää DR markkinoilla lähes ilman mitään investointeja. Vähintään tämä osuus potentiaalista tulisi valjastaa tuottamaan ylimääräistä arvoa.

PREFACE

This thesis was written during the seven months I spent at the UPM Rauma paper mill. The job challenged me fairly and also rewarded at the end.

I would like to thank a few people of the professional support and advice I received during this study. First of all, I would like to thank Timo Pitkänen, Jarkko Nyrhinen and Mikko Vuori from UPM for the opportunity to do this thesis. Also from UPM, I would like to give special thanks to Kari Hinkkanen, Sari Siirtola and Tapio Riikilä for the priceless counsel during the study. And last but not least, I would like to thank my examiner, Professor Pertti Järventausta for the interest and new perspectives that he shared with me during this study.

I would also like to express my gratitude to my family and fiancée. Without you I am nothing but an empty shell.

Matti Aro, Rauma/Tampere
15th of September 2017

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LIST OF ABBREVIATIONS AND NOTATIONS

AC	Alternating current
A/C	Air conditioning
aFRR	Automatic Frequency Restoration Reserve
BRP	Balance Responsible Party
CHP	Combined Heat and Power
CO2	Carbon dioxide
DR	Demand Response
e.g.	For example (lat. exempli gratia)
ElspotFI	Finland's regional electricity price
ENTSO-E	European Network of Transmission System Operators for Electricity
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve for Disturbance
FCR-N	Frequency Containment Reserve for Normal operation
FG	Fingrid
HPAC	Heating, Plumbing and Air Conditioning
HVDC	High-voltage direct current
i.e.	In other words (lat. id est)
IT	Information technology
mFRR	Manual Frequency Restoration Reserve
MISO	Midcontinent Independent System Operator
NGC	Nordic Grid Code
OL3	Olkiluoto 3
OTC	Over the Counter
SAP	Systeme, Anwendungen und Produkte in der Datenverarbeitung Aktiengesellschaft
TMP	Thermo-Mechanical Pulp
TSO	Transmission System Operator
UPM	United Paper Mills
USD	United States Dollar

1. INTRODUCTION

We live in a period of transition. A century-long industrial development has led us to a point where we can no longer excessively strain the resources of our planet. Burning of fossil fuels such as oil, coal and natural gas is the largest source of emissions of carbon dioxide, one of the greenhouse gases contributing to global warming (NEIC 2016). Moreover, fossil fuels are an exhaustible resource meaning that our planet will eventually run out of them, more precisely, within the next century (Shafiee et al. 2008). In the same time power consumption is expected to increase, so the need for changing the ways to generate electricity is evident (EIA 2016, Brauner et al. 2013).

A global movement towards increasing renewable power generation is visible with various investments made in photovoltaic and wind power plants around the world (McCrone et al. 2016). Despite the dramatic decline in global fossil fuel prices between June 2014 and January 2016, the world saw the largest capacity additions in renewables in 2015 (REN21 2016). In 2015, global investment in new renewable power capacity was 285,9 billion USD which is more than double the 130 billion USD allocated to new coal- and natural gas-fired power generation capacity (REN21 2016).

Unfortunately the transition from fossil fuels to renewable energy raises a new challenge for power system operators. The classic disadvantages associated with fossil fuels such as the environmental burden it composes are replaced by risks relating to the varying availability of natural resources. The operating hours of renewable power generation depend on the availability of water, wind and sunshine so they cannot be controlled by the demand. This makes it challenging to maintain the necessary balance in power grids between electricity production and consumption. (EC SWD 2013, Sorri et al. 2016)

The balance between supply and demand in electricity networks has traditionally been achieved mainly by controlling the output power of generators (THEMA 2014). However, with the renewables becoming more in common we are losing the controllability of the production side. A certain level of flexibility in the system is still necessary so the focus is now being directed more to the demand side. (Nordel 2004).

In Finland, some consumption units from large-scale industry have already acted as power reserves for a long time. The reserves are used for securing the power balance in the grid (Fingrid 2017b). However, the unharnessed potential of demand side flexibility is still significant (Borggrefe et al. 2010, Farin et al. 2005). A recent idea on the electricity markets is to combine, or aggregate, small-scale consumption and production units into a larger entity, which could participate the reserve markets as a package, acting as a virtual power plant (VPP). (Eisen J.B. 2012, Rahimi et al. 2010, Versick et al. 2010)

1.1 Energy field in transition

The Ministry for Employment and the Economy in Finland has stated that carbon-neutral society is Finland’s long-term target. This is aligned with the energy and climate policies around Europe. Actions on government level have already been taken towards increasing renewable energy production. In 2010, a decision was made in Finland to support wind power along with other forms of renewable energy. The feed-in tariff for wind power aims at increasing Finland’s wind power capacity to 2,500 MVA by 2020. The development of built wind power capacity from the recent years shows that if the trend continues, the 2,500 MVA target will be met during 2018. (TEM 2013, STY 2017)

Changes in the structure of electricity production composes challenges for power system operation. Renewable energy sources are increasing and the traditional coal-fired plants are being closed. An increasing percentage of the electricity production is so-called rigid, such as weather dependent wind and solar power. Almost 1 GW of flexible condensing power has disappeared from Finland's electrical system in recent years. The situation is parallel to the rest of Europe. Support for renewable energy has pushed down the price of electricity so much that traditional power plants that are independent of weather conditions are no longer economically viable. Increased amount of nuclear power production has also contributed to this due to its low unit price. Also due to nuclear powers low unit price, it is run as a base load in power production which means that it too increases the need for flexible capacity elsewhere. (Fingrid 2016)

As a result of the electricity market reform in 1995, the operating environment in electricity production has been experiencing substantial changes. The competition has become more tight in the recent years as Finland becomes more involved in the joint Nordic and –European electricity markets. The competition has led to shortened delivery contracts and increased operational risks. The market reform has also increased the importance of environmental factors such as environmental taxes and emission limits. (Partanen et al. 2016)

Electricity production is facing a change, energy policy is turning greener and self-sufficiency of electricity is attracting many countries when the availability of imported electricity is not guaranteed in the long run. Changes in the power system can also be seen with a wide integration of automation in power grids. How these changes will influence the electricity markets and the system operator’s willingness to pay for flexibility is yet to be seen. Development in different areas of the power system drives the value of flexibility in opposite directions. Electricity production side is losing its controllability but then automation and new power connections to water reserves in the north diminish the overall need for demand side flexibility. This creates uncertainty to the future demand of flexibility. (TemaNord 2014)

1.2 Objective and scope of the thesis

This thesis was commissioned by UPM-Kymmene Corporation (UPM), which is a Finnish forest industry company with a revenue around 10 billion euros and production activity in 12 countries. UPM is going through a transformation to ensure sustainable value creation in the long term. Their aim is to improve profitability and to generate growth which has led to a complete change in the organization structure (UPM 2017). The new organization structure composes of six separate business areas, each targeting top performance in their respective market: UPM Biorefining, UPM Energy, UPM Raflatac, UPM Specialty Papers, UPM Paper ENA and UPM Plywood.

UPM Paper ENA Oy's Rauma mill is located by the sea on the west coast of Finland, near Rauma city center. Metsä Fibre Oy's pulp mill, Forchem Oy's tall oil distillation plant and Rauman Biovoima Oy's biofuel power plant are also based at the mill site. UPM Paper ENA Oy produces the raw and chemically treated water used at the site, and is responsible for the treatment of the site's industrial and municipal wastewaters.

The Rauma mill has three paper machine lines, a fluff pulp line, a twin-line debarking plant, two grinderies, two TMP plants, a surface water treatment plant and a biological effluent treatment plant. The paper machines manufacture magazine papers – one of the machines produces uncoated, supercalendered paper, while the other two produce lightweight coated paper. The paper made in Rauma is used in magazines, sales catalogues and advertising products. In addition to paper, the mill produces fluff pulp for the production of hygiene products and tabletop products. Production capacity is 960,000 tons of paper and 150,000 tons of fluff pulp.

Objective of this thesis was to map out the flexible electrical power capacity of Rauma mill, power plant and water treatment plant. In addition, the aim is to create a more widely implementable procedure for identifying flexible loads and to consider different ways to aggregate loads to be offered to different markets. The scope of this thesis is mainly in Fingrid's power reserves and UPM Rauma mill's potential to participate there. When considering different ways to maintain the necessary balance in the power grid only Demand Response is discussed in detail. Out of the scope is left, for example, the storing of electricity in batteries.

1.3 Structure of the thesis

This thesis begins with an introductory chapter that introduces the research topic and outlines the background on the subject. Then, the introduction presents the objective and scope of the thesis and what has been left out of it. Also the method developed during this thesis is shortly presented in introduction.

The second chapter covers the Nordic electricity market and the major characteristics it holds around Demand Response. This chapter also presents information about electricity pricing and the production methods. The aim of this chapter is to familiarize the reader into special features the joint Nordic electricity system has.

Next chapter comprises the main theoretical background of maintaining the necessary power balance in the power grid. In this chapter the importance and challenges of maintaining the power balance is impressed by way of examples. Also in this chapter, the means of securing the power balance are presented. Fingrid's power reserves are also produced.

The fourth chapter deals with Demand Response. First, the meaning of DR is opened and then the need for it is discussed in detail. This chapter presents the concepts of Smart Grid and Datahub as enablers of DR and also compares the possible benefits and challenges of operating in DR. Finally in this chapter the participation in the reserve markets is described.

Chapter 5 presents the case study that was conducted during this thesis. It starts by introducing the reader to the company that subscribed this work. Next is presented the tools and methods developed during this thesis. The methods aim at evaluating the DR potential of an industrial company.

As it becomes clear during the thesis, economical benefit is the driving force behind implementing DR actions. Chapter 6 ponders the overall benefits of participating in the reserve markets. Also initial costs and challenges of participation are discussed.

In this phase, the results of the study are presented. Chapter 7 answers what were the aims of this study and did the results answer the initial questions. The results are presented in function venue level and finally, the results are summarized in one table.

Chapters 8 and 9 discuss the conducted study and make conclusions of it. Challenges during the study are pondered and future works suggested. Ultimately, a short summary of the whole study is produced.

2. NORDIC ELECTRICITY MARKET

Finland was one of the first European countries in 1990s where electricity market were released to open competition. Since the reform, generation, sale and transmission of electricity are separated into different businesses and end-users are able to tender out their electricity vendor. In the wholesale market of electricity, tendering was possible only within Finland at first. In 1999, Finland joined the joint Nordic electricity exchange, Nord Pool. After that, large industrial end-users were able to buy electricity also from Sweden and Norway. Today, Nord Pool includes seven countries in total; Finland, Sweden, Norway, Denmark, Estonia, Latvia and Lithuania. (ElFi 2017)

The Nordic electricity market is characterized by a strong variation in the amount of electricity produced by hydropower and large variation in electricity consumption, which is reflected in the volatility of electricity prices. These specificities of the market create need for a flexible wholesale market, which is able to manage large fluctuations in both electricity production and consumption. In Finland, electricity accounts for about a quarter of the final energy use and industry accounts for about half of the electricity use. Figure 1 shows the distribution of electricity usage by user groups in 2015, when the total electricity consumption was 82.5 TWh.

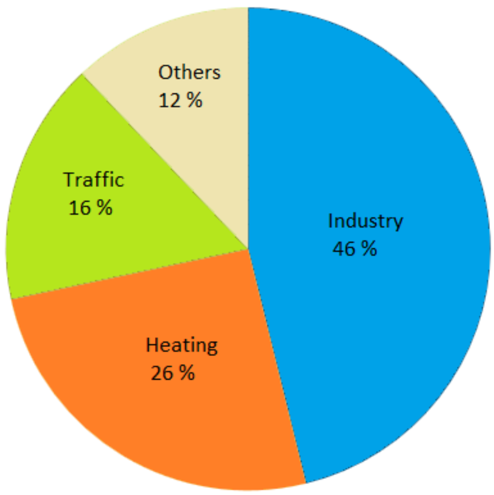

Figure 1 Electricity usage by user groups in 2015 (Partanen et al. 2016)

As it can be seen from Figure 1, the biggest electricity user group in Finland is industry with a share of almost half. The forest industry is the largest field of industry in Finland with a cut of over 50 % of the total electrical energy used by industry. Households alone use about one fifth of the total use of electrical energy and the rest is divided between services, public consumption and agriculture. Electricity transmission losses account for about 3 % of the total demand. (Partanen et al. 2016)

2.1 Electricity trading

Electricity wholesale is traded on the electricity exchange and the OTC (Over the Counter) market. Electricity producers in Nordic and Baltic countries trade physical electricity through both the Nordic power exchange –Nord Pool and the OTC market with bilateral agreements to major customers and retailers of electricity. After the electricity reform, the sale of electricity is no longer a licensed activity, so the sector is free for new entrepreneurs. Electricity trade can be divided into wholesale trade targeted for the larger operators and retail sales to smaller ones like households. (Partanen et al. 2016)

Trading on electricity exchange is divided into physical and financial products. Trading on the physical products in the electricity exchange always leads to actual supply of electricity, whereas trading on financial markets leads only to an exchange of money. In the Nordic and Baltic countries, trading that leads to supply of physical electricity is executed on the Nord Pool Spot market and derivative products on the Nasdaq Commodities financial market. Nord Pool Spot market is divided into day-ahead trading (Elspot) and intraday trading (Elbas). (NP 2017)

The Elspot market is traded on a fixed electricity supply of 0.1 MWh and its multiples for the next delivery day for a certain hour. Also various block products i.e. bids to buy or sell a certain amount of energy in consecutive hours can be used. Operators on Elspot market can define block length, but the minimum length is 3 hours. The offer includes at least the information of the amount of energy to be purchased or sold and the price for that energy. Block bids will only be activated if both the price and the volume criteria are met. The Elbas market acts as a continuing post-market for Elspot trading. Elbas is open 365 days a year and 24 hours a day offering hourly and block products. Elbas is primarily intended to control exceptional situations in balance sheet management. (Partanen et al. 2016, NP 2017)

2.2 Price of electricity

In the Nord Pool Spot market, the price of electricity is determined for each hour of the next Elspot day (CET 00 - 00), based on the purchasing and selling offers provided by market participants. The offers concern a certain amount of electricity at a certain hour with a certain price. When the time limit for submitting the tenders has expired, they are combined within a certain hour and demand and supply curves are created, as shown in Figure 2. The point where demand and supply curves meet is determined to be the system price at which all trading takes place. Sales and purchase offers are made by sealed-bid method. Sealed-bid method in this context means that tenders are made without knowing the offers made by other participants. This tendering procedure ensures the efficient functioning of the market by using the production forms starting from the lowest price. (Partanen et al. 2016)

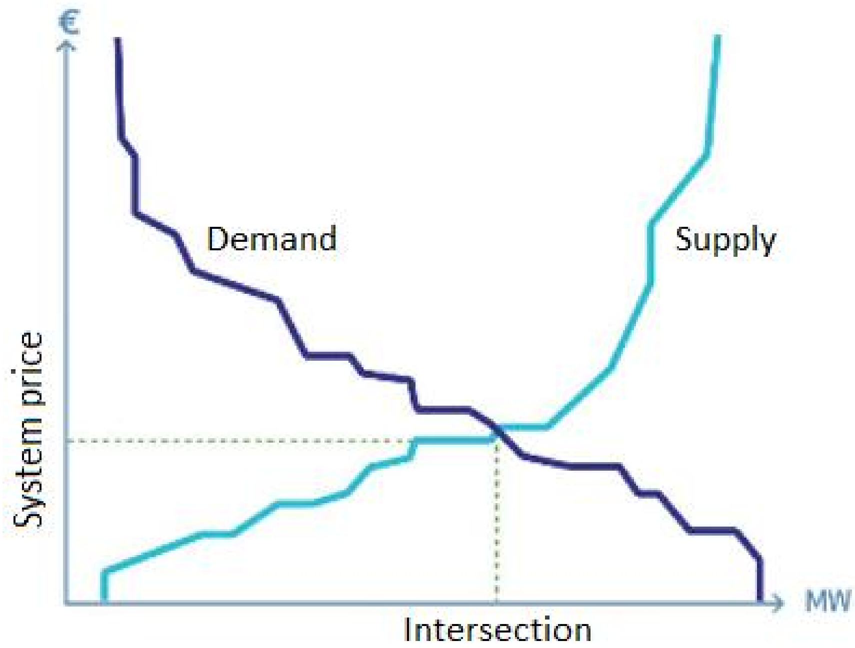

Figure 2 The system price is based on demand and supply (NP 2017)

The market price, i.e. the system price, is set on the basis of tenders as shown in Figure 2. The system price corresponds to the variable costs of the most expensive production method that was needed to cover electricity demand. The variable cost of this form of production determine the existing marginal cost for electricity. When the production run order is organized starting from the method with lowest marginal cost and ending to the most expensive one, electricity production and consumption meet at the lowest possible price at all times. Figure 3 illustrates two different cases of price formation, with lower electricity demand in summer and higher in winter. In the summertime, lower demand is covered with primary production, which typically has high start-up costs but low variable costs. Therefore, it is economically viable to run such production as much as possible. In winter, electricity demand is higher and the production capacity has to be more widely utilized. (Partanen et al. 2016)

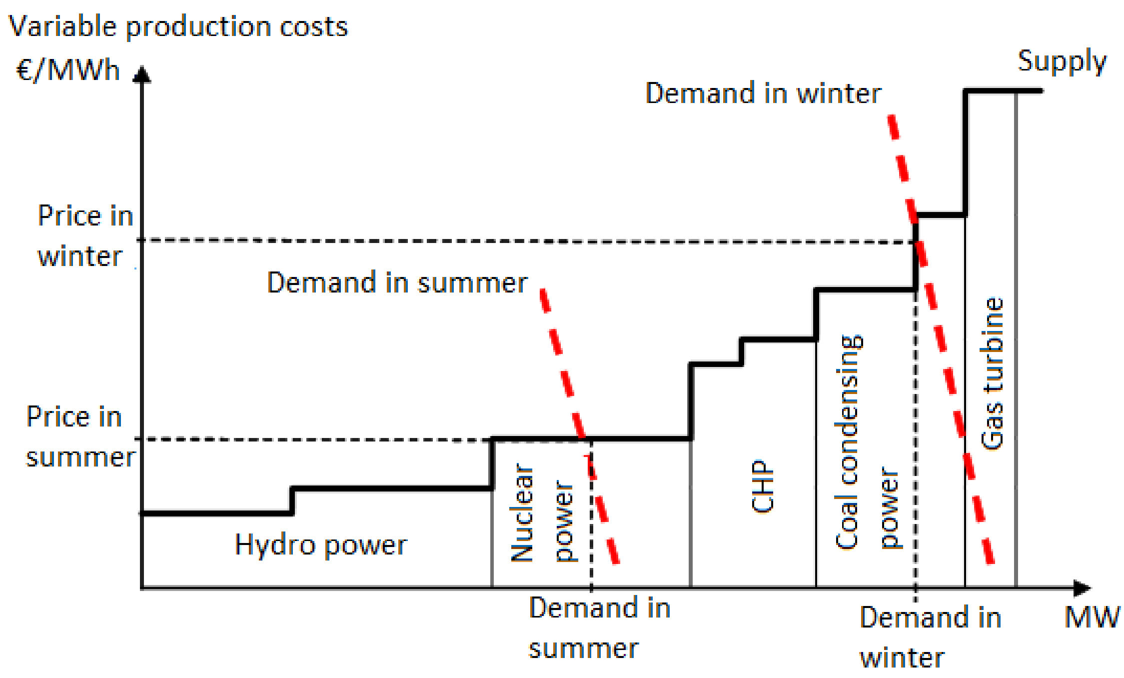

Figure 3 The formation of the system price of electricity in summer and in winter (ELFI 2017b)

The system price reflects the most expensive production method needed to meet demand. The formation of the system price does not take into account the physical constraints of the transmission network. The Nord Pool Spot area has 14 regional bidding areas, shown in Figure 4. If the transmission capacity is not sufficient for a market-based transfer between bidding areas, the market is divided into these 14 regional areas where the price can be different from the system price. The price will rise in areas of underproduction and fall in areas with overproduction.

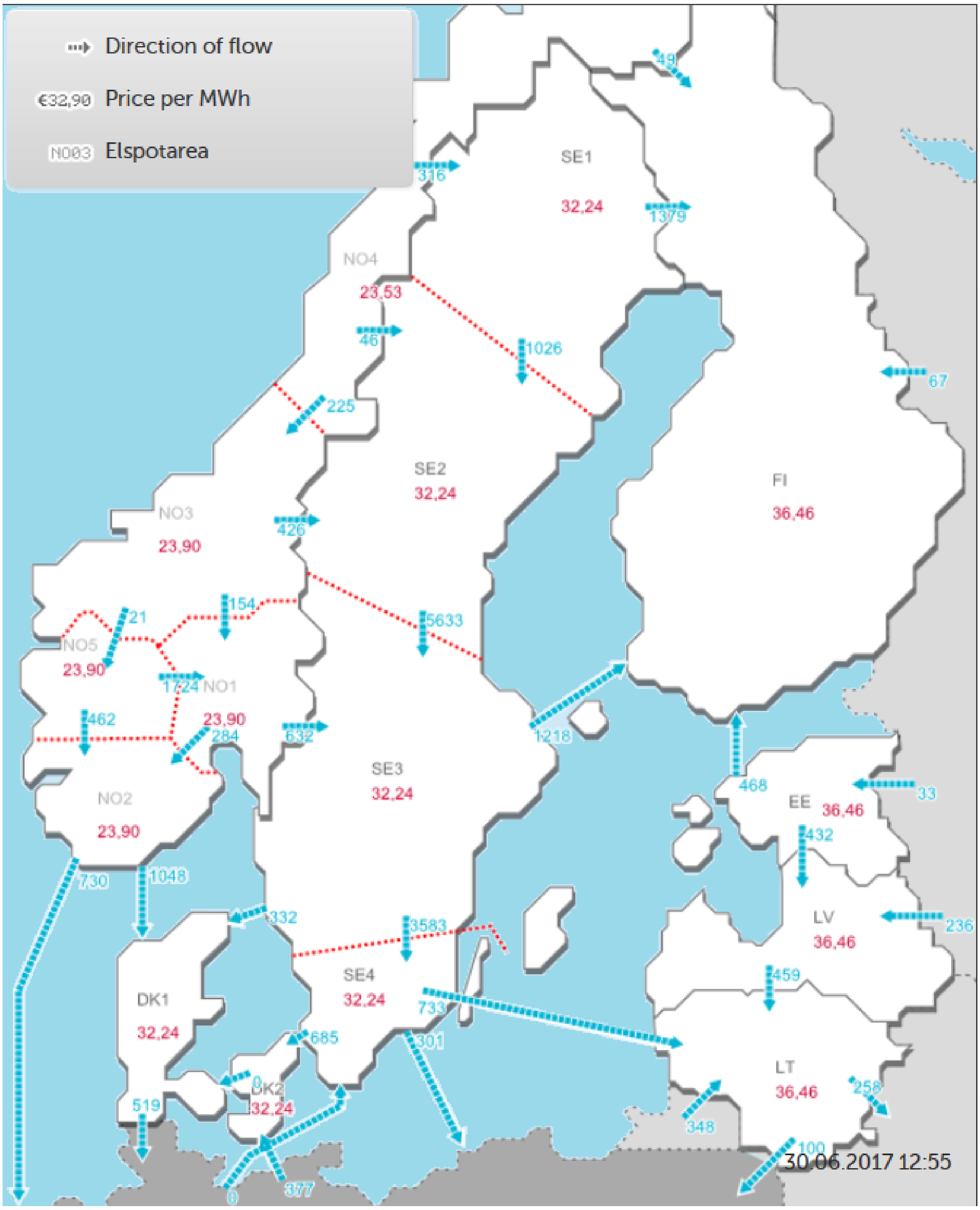

Figure 4 Regional electricity prices and power flow between regions (Statnett 2017)

Finland consists of only one region in the Nord Pool market, so there is only one regional price in Finland. That serves as a reference price in the balance and power regulation trading in Finland. The system price is used as a reference in Nasdaq Commodities' financial products. We can see from Figure 4 that 30.6.2017 12:55 Finland's regional electricity price, ElspotFI, was higher than the regional prices in Norway and Sweden. It means that transmission capacity from Norway and Sweden to Finland at that time was not sufficient for the cheap hydropower to be transferred to Finland, so more expensive forms to produce electricity had to be used in Finland to cover the demand. When demand in Finland is at its highest, part of the supply comes from the neighboring countries, usually from Sweden and Russia.

The price of electricity for end-users consists of the cost of purchasing electricity, electricity transmission and taxes. In a short term the shares of electricity transmission and taxes are relatively constant with a certain consumption. However, the share of purchasing electricity can vary greatly in a very short time, because the price of electrical energy is dependent on several variables. The transmission price consists of the costs of electricity transmission in the main and distribution grid. For a household customer, the purchasing of electrical energy accounts for just over a third of the total cost of electricity. The share of electricity transmission is a bit under a third and taxes account for the rest.. (Partanen et al. 2016, Vattenfall 2017*)*

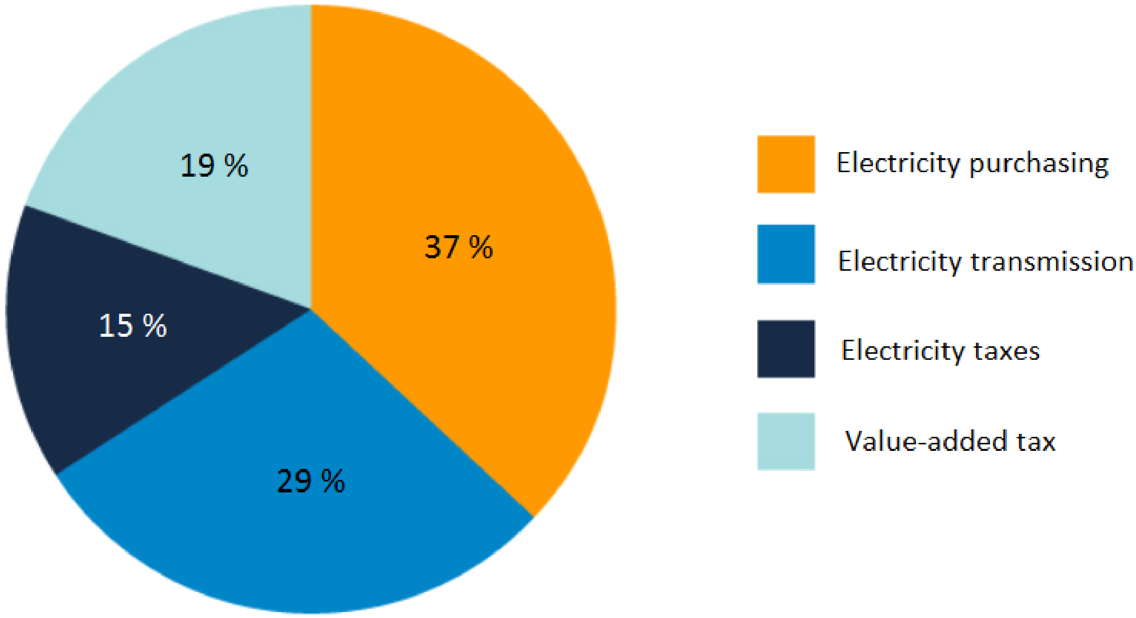

Figure 5 Electricity price formation for an average household customer (Vattenfall 2017)

For households that use electrical heating and for industrial customers, the share of purchasing electrical energy is higher than shown in picture 5, and on the other hand, the shares of electricity transmission and taxes are smaller.

In the electricity market the price of electricity indicates the occurring balance between production and consumption. In the real-time markets, i.e. the regulating power market and reserve markets, the price can vary at huge range, for example due to a disconnection of a large production unit. The counter actions after the fault have to be executed fast. More production needs to be added to the network or alternatively same amount of consumption to be disconnected from the grid. An increased price in the real-time market reflects the increased need for balancing. (Fingrid 2017e)

As stated before, electricity price is dependent on the available supply. When in the Nordic electricity market about half of the electricity produced is based on renewable hydro power, the price is also strongly affected by existing water reserves. The price of electricity is also influenced by weather, fuel prices, the state of large power generation units, the surrounding markets and their price levels, and the price of emission rights (ELFI 2017). In Figure 6 below, the effect of water resources in the price of electricity is shown.

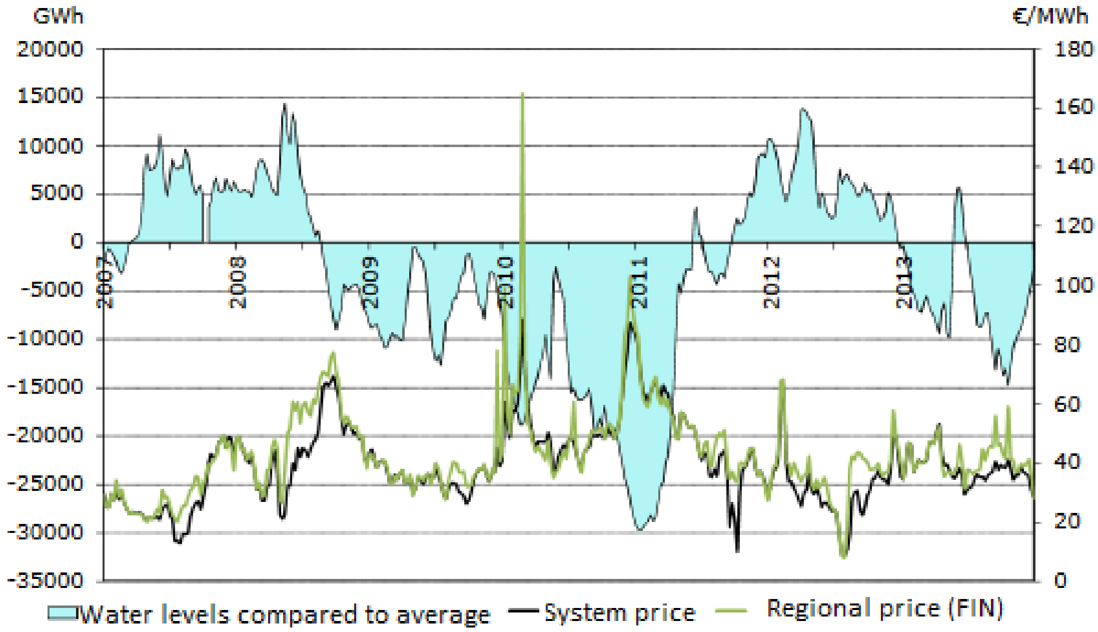

Figure 6 The effect of water levels on system price (Partanen et al. 2016)

As we can see from Figure 6, when the water levels have been on very low level, it has had an increasing effect on system price. During long dry seasons when there is not that much hydropower available, the electricity has to be produced by other, more expensive ways.

2.3 Electricity production methods

Electricity purchases by type of production in Finland in 2015 is shown in the Figure 7. CHP stands for Combined Heat and Power.

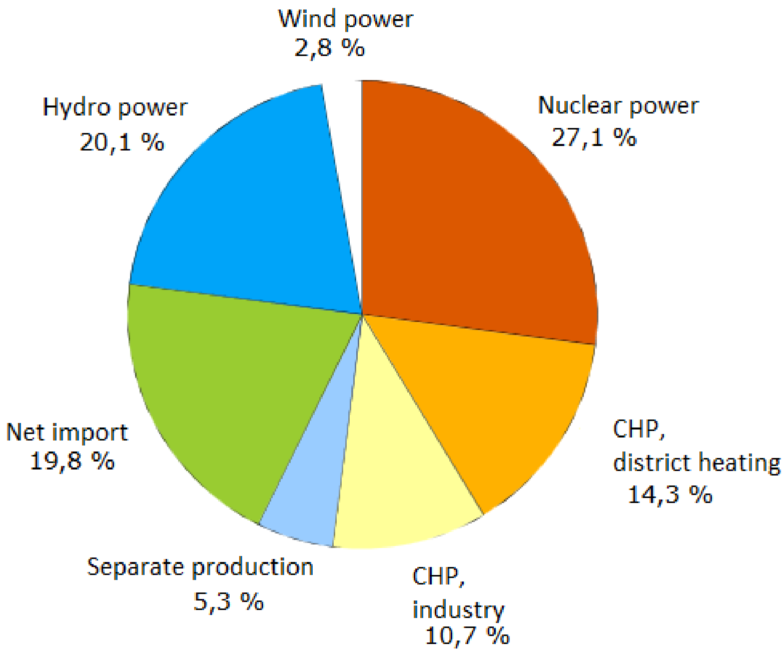

Figure 7 Electricity purchases by type of production in Finland in 2015 (Partanen et al. 2016)

Figure 7 shows that production structure in Finland is versatile. In 2015 the production share of nuclear power was about a quarter, the same as that of CHP. Hydropower accounted for about 20 % and was of the same size as net imports. The total electricity consumption in Finland in that year was 82.5 TWh. (Partanen et al. 2016)

The amount of electricity produced in CHP plants varies, as the primary product there is heat and the annual demand for heat varies with prevailing weather. The electricity generated in hydropower plants is dependent on the annual water levels. The water situation is also reflected in the amount of electricity produced in condensing power plants. When the water situation is good, hydropower is used more and condensing power respectively less. (Partanen et al. 2016)

3. MAINTAINING POWER BALANCE

The electric power system consists of power plants, loads and the power network connecting them. The purpose of the system is to transfer the generated energy from power plants to electricity users as reliably and economically as possible. Fingrid is a Finnish electrical power transmission system operator (TSO) and owns about 14,000 kilometers of high-power transmission line and over 100 substations. The high-power transmission network, also known as the main grid, is a trunk network covering the entire Finland. All distribution networks are connected to main grid, as well as major power plants and industrial plants. The power system in Finland is part of the inter-Nordic power system together with the systems of Sweden, Norway and Eastern Denmark. This means that our grids are synchronically connected and the grid frequency is same in all parts of this system. (Fingrid 2017a)

Maintaining the balance between production and consumption is a continuous process which can be thought to begin initially when an electricity consumer or producer makes a tender where it offers to consume or produce a certain amount of electricity at a certain time and price. Based on these tenders, the initial view on the future balance between electricity demand and supply is created. However, especially the electricity consumers cannot predict their consumption well enough in advance so there is always a small imbalance between consumption and production. Also the weather dependent forms of electricity production are challenging to forecast. TSO is responsible for maintaining the power balance, so it constantly monitors the grid frequency and takes action when needed. Primarily the imbalance is sought to mitigate by electricity trades through regulating power market. The final level in maintaining the balance is TSO's pre-purchased reserves which regulate the balance partly automated. More about regulating power market and power reserves will be discussed later in this chapter.

European power grid operates at 50 Hz when electricity production and consumption are in balance. If consumption exceeds the level of production, frequency drops below 50 Hz. If the production is again larger than the consumption, increases the frequency above 50 Hz. Under normal circumstances, the frequency is allowed to vary between 49,9 and 50,1 Hz. The less the frequency varies, the better the quality of electricity. The frequency should be kept as constant as possible to prevent changes in rotational speed of synchronous motors and short circuit motors. If the imbalance grows too high, increases the risk for total power system collapse that could lead to a nationwide power outage. The frequency of the power system is controlled with different actions.

Fingrid, as a TSO in Finland, is responsible for the national balance sheet management in Finland, meaning that they have to make sure that the same amount of electricity is produced and consumed at every moment. Modern technology cannot be used to store large amounts of electricity economically viable, so power balance is maintained by controlling production and consumption. Some adjustments are done automatically and some are handled manually. Figure 8 shows how automatic *primary adjustment* tends to keep the frequency close to 50 Hz and how the manual *secondary adjustment* is activated when the frequency deviates enough from the rated value. (Partanen et al. 2016)

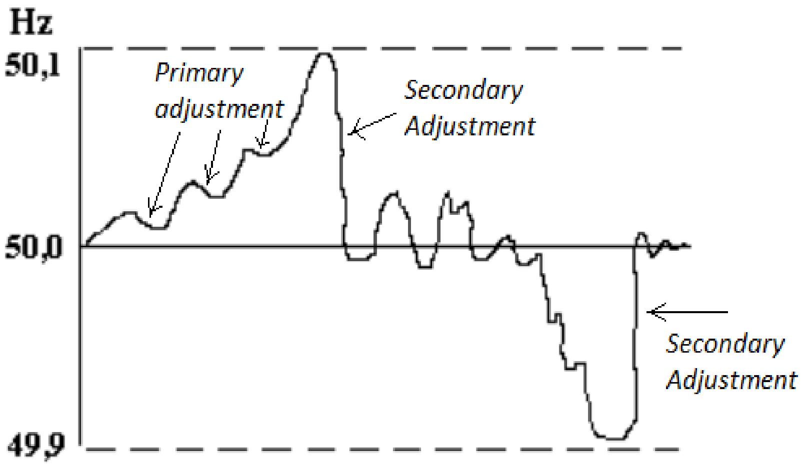

Figure 8 Primary and secondary adjustment in operation (Partanen et al. 2016)

Figure 8 illustrates the grid frequency fluctuating around 50 Hz. Primary adjustments are small corrections that tend to keep the frequency between 49.9 and 50.1 Hz. If the frequency still reaches the limits of normal operation the secondary adjustments are made.

3.1 Forecasting consumption and production

The special feature of electricity as a product is that electricity produced at any given moment must be consumed at the same time, as its cost-effective storing is still impossible. For that, the electricity market differs from other commodity markets (oil, gas, coal, etc.), where current demand and supply may be unbalanced without significant impact on use, availability or price. This major difference is due to the low cost of storing these products. (ELFI 2017)

Electricity consumption has to be predicted in many business areas of the electricity market; production, transmission and distribution, and sales. Forecasts of consumption are important because supply has to be planned and the sufficiency of transmission capacity ensured based on that. In electricity trading, one prerequisite for a profitable business is the design of sales and purchases as accurately as possible so that the open position does not grow larger than what is planned. Open position is for example the part of power plants production that is not sold in advance. When predicting future consumption, the most interesting things to consider are active and reactive power, peak power, time variation in consumption, total amount of needed energy and losses on the basis of this information. Despite the uncertainty involved in predicting consumption, it must be possible to buy and sell as much electricity as needed. This requires a functioning physical market, which constitute a credible reference price for the electricity traded. (Partanen et al. 2016)

The demand for electricity varies during the day, week and year. In Figure 9, the power flow through a small 110/20 kV substation in the first week of January is shown. It can be seen from the figure that power going through the substation is not constant, but varies depending on the time of day and week.

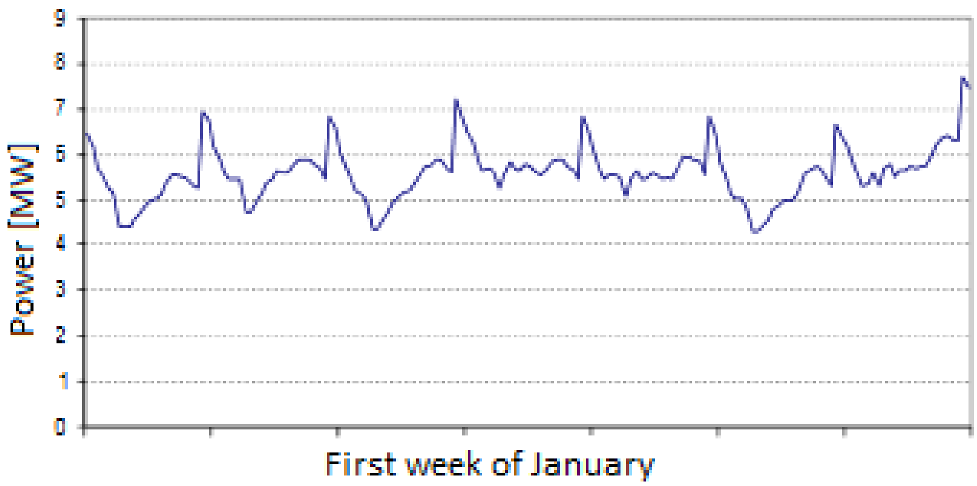

Figure 9 Power flow through 110/20 kV substation (Partanen et al. 2016)

Fluctuations in the electricity consumption, such as shown in the Figure 9, must be predicted. The electricity generation capacity has to be at least equal to the peak power demand. Strong variation in the consumption of electricity must be taken into account also in the structures of power grid. Although the demand could be met with supply, the power has to be transmitted from the production to consumption without excessive losses and the quality of electricity kept at an acceptable level.

In large scale the consumption side is relatively easy to predict because it is quite cyclic. Consumption peaks usually occur at the same time every day. First peak in consumption can be seen in the morning when the vast majority of people wake up and the second one occurs when they get out of work. Traditionally, the production side has been operated in accordance to the consumption. With the changing production structure, the production side can no longer adapt to changes like it used to, because it is more weather-dependent than before. For example, a wind turbine requires a certain wind speed in order to work and produce electricity (see Figure 10), whereas too strong wind stops the turbine so that it will not break. The next two figures (Figure 10 and 11) illustrate the power output dependency on prevailing wind.

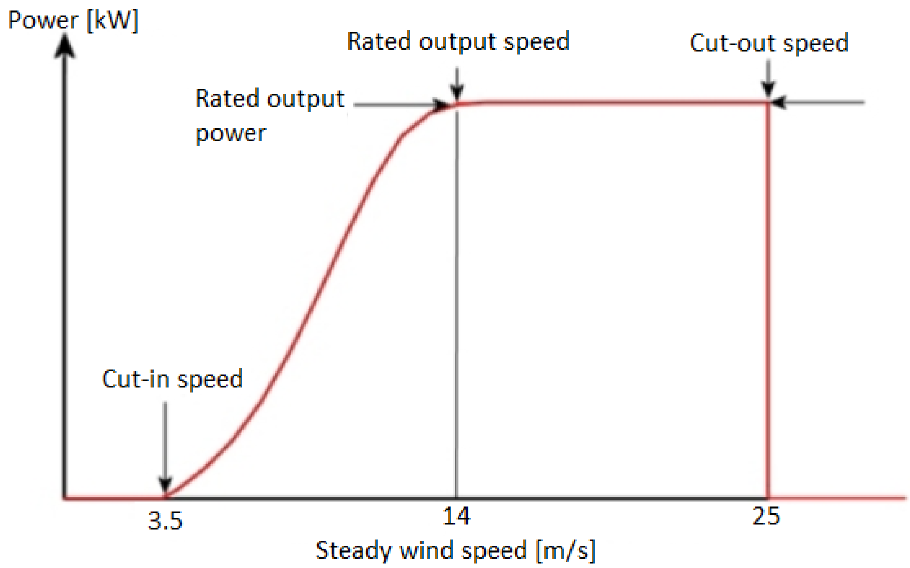

Figure 11 Typical wind turbine power output with steady wind speed (WPP 2017)

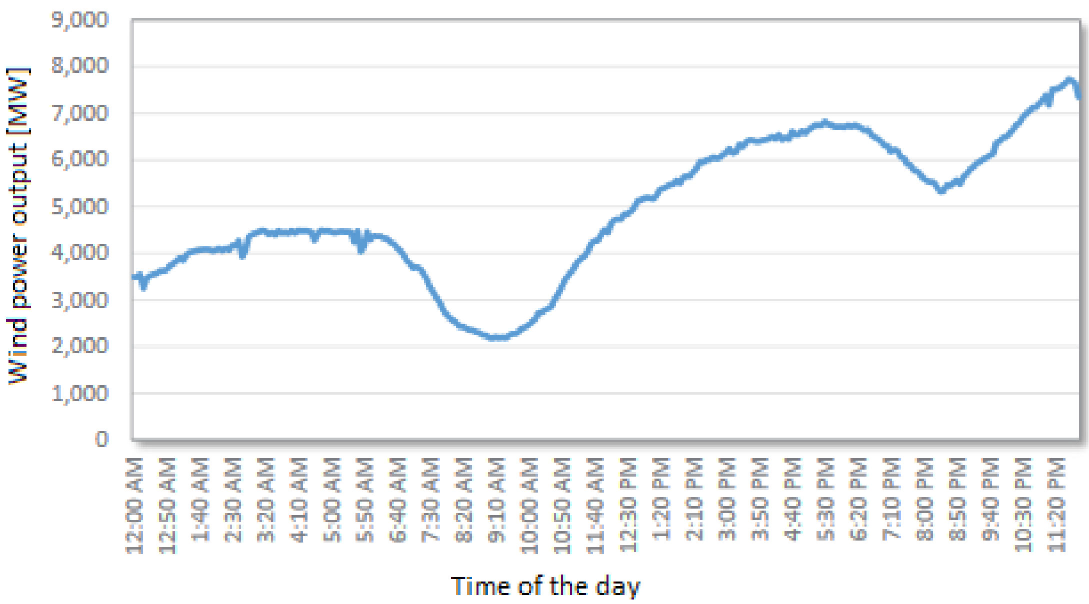

Figure 10 Wind power output of 24 hours in July 18, 2013 (Better Energy 2015)

As we can see from the Figure 11, the output power of wind turbines vary greatly during 24 hours. The variation is due to changes in wind speed. The figure shows the wind power production from the Midcontinent Independent System Operator (MISO) operating area in the central United States on July 18, 2013. The graph shows wind power output ranging from 2 to 8 GW within one day. For this type of production, it is necessary to find significant amount of flexible capacity capable of balancing the fluctuations caused by wind power production.

3.2 Operating reserves

Fingrid as a TSO in Finland is responsible for the operational reliability of the power system. To succeed in this and to maintain the necessary balance, Fingrid needs to have operating reserves and other ancillary services, including frequency control and reactive power support. Operating reserve in this context is a service for the provision of active power. The provision can be for up-regulation or down-regulation and the reserve can be activated automatically or manually. Up-regulation means raising the grid frequency by increasing electricity production or decreasing consumption. Down-regulation is the opposite action, decreasing the production or increasing the consumption. These reserves are formed from available and controllable active power capacities from production plants and consumption units. Fingrid acquires different reserves to meet different challenges in power balance maintenance. (Fingrid 2017d, Nordel 2004)

Fingrid takes care of the balance, for example, by activating balancing bids from the regulating power market and by reserving capacity from market operators. Additionally to Fingrid's capacity reserves there is also a peak load reserve system in Finland. The peak load reserve system ensures the reliable supply of electricity in times when the estimated power demand exceeds the estimated power supply. Production plants as well as loads that are flexible can act as a peak load reserve system. Capacity reserved for the peak load reserve cannot participate in any other commercial market to ensure availability at all times. The reserves that are managed by Fingrid in order to maintain the balance are presented in chapters 3.2.1 and 3.2.2. (Fingrid 2017d)

3.2.1 Frequency Containment Reserve

Frequency Containment Reserve (FCR) is meant for continuous frequency control and is automatically activated when the grid frequency changes enough from the rated. Traditionally most of the reserve is acquired from the power production side, but now when the overall flexibility on that side is diminishing, the demand side has to engage more heavily than before. The Frequency Containment Reserve includes Normal operation (FCR-N) and Disturbance (FCR-D) reserves, both automatic and frequency controlled. They are activated automatically when the frequency deviates enough from 50 Hz. The two FCRs differ from each other in terms of operating range and activation rate. Figure 12 illustrates the operating range and activation rate that is required from capacity operating as FCR-N and FCR-D in case of a sudden frequency drop.

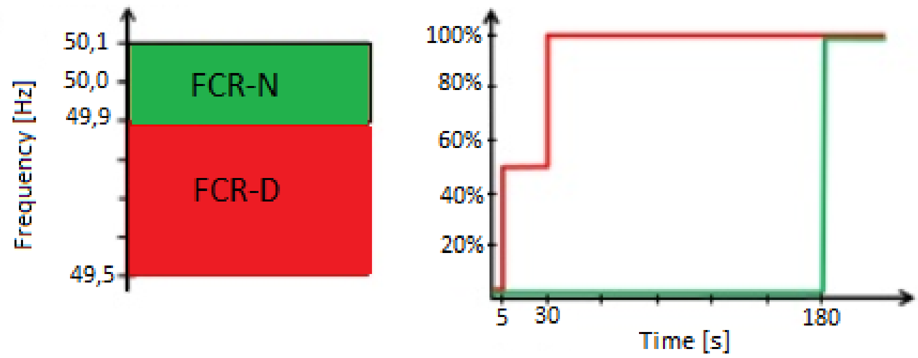

Figure 12 Operating range and activation time in a case of sudden frequency drop (Fingrid 2017i)

Figure 12 illustrates the operating ranges and activation times of both FCRs. As we can see from the left graph, FCR-N operates in range of 50 ± 0.1 Hz and FCR-D in 49.5 - 49.9 Hz. From the adjacent graph, the requirements for operating time can be seen. According to present requirements the FCR-N capacity must be fully activated in three minutes after a frequency change of 50 ± 0.10 Hz. FCR-D capacity has to act significantly faster. In the event of a frequency drop to 49.5 Hz, caused, for example by a momentary loss of production, the capacity has to operate as follows:

- 50 % of FCR-D in each subsystem shall be regulated upwards within 5 seconds
- 100 % of FCR-D shall be regulated upwards within 30 seconds. (Fingrid 2017i)

FCR-N is meant to compensate the normal fluctuations in grid frequency. It must respond to frequency deviations almost linearly in the frequency range of 49.90 to 50.10 Hz so that the dead zone of the frequency control is 50 ± 0,05 Hz at most. The control must be fully activated in three minutes after a frequency change of 0.10 Hz (see Figure 12). There is a total of 600 MW of FCR-N maintained in the joint Nordic system for the frequency regulation. This reserve is annually divided between TSOs in the joint Nordic system in relation to the total consumption in each country. Finland's share of this is 140 MW in 2017 and it is all covered up with production, so at present there is not any consumption capacity operating on FCR-N. (Fingrid 2017i)

FCR-D is intended for the management of unexpected disturbances. In the Nordic Grid Code (NGC), it is stated that there has to be a frequency controlled disturbance reserve of such magnitude and composition that dimensioning faults will not entail a frequency of less than 49,5 Hz. It is also stated in NGC, that upward regulation of the frequency controlled disturbance reserve must not give rise to other problems in the power system (Nordel 2007). This ladder one has been a problem with some reserve units in recent years, as it became clear at the Fingrid's annual reserve days in May 2017. The needed FCR-D capacity is defined on weekly basis to match a possible disconnection of the largest single production unit minus the natural control power of the power system. The grid's natural control power is a phenomena where the power demand of electrical loads decrease in correlation with decreasing grid frequency in a case of power production disconnection. The grid's natural control power is around 200 MW. Total of 1200 MW of FCR-D capacity is maintained under normal operating state in joint Nordic power system and Finland's share of this is around 260 MW. (Fingrid 2017i)

Fingrid acquires the frequency controlled reserves from the domestic yearly and hourly markets, from Estonia and Russia by HVDC links and from other Nordic countries. An operator can offer its controllable capacity to the yearly and/or hourly market if the capacity is located in Finland and fulfills reserve requirements. Technical requirements are same for both markets but other features may vary. (Fingrid 2017f)

Switching the third nuclear unit to the electrical system in Olkiluoto will be a historical landmark. The moment when electricity supply from the world's largest nuclear plant starts, rises the dimensioning fault of the electrical system, i.e. disconnection of the largest production unit that the TSO has to be prepared, from the current 865 MW to 1300 MW. The output power of OL3 is 1600 MW but due to the system protection its effect falls to the level of 1300 MW. If OL3 happens to disconnect from the network, the automatic system protection immediately disconnects 300 MW of consumption from the agreed industrial operators. (IAEA 2012)

3.2.2 Frequency Restoration Reserve

Frequency Restoration Reserve (FRR) is slower activated active power reserve and is meant to release activated FCRs back into use and to restore frequency back to its rated value. The FRR includes both automatically and manually activated reserves. Automatically activated FRR (aFRR) activates automatically due to a deviation in frequency. Activation happens based on TSO's calculated and sent power change signal. Manually activated FRR (mFRR) includes the regulating power market. The activation time is up to 15 minutes and is done by Fingrid. Tenders from regulating power market are activated if necessary in times of normal state and during disturbances.

Automatic Frequency Restoration Reserve (aFRR) is mutually agreed to be maintained up to 300 MW in the Nordic countries in predefined morning and evening hours. Fingrid purchases aFRR reserve from the hourly market. Operators with applicable capacity can submit bids to the hourly market and the bids can be either for upward or downward adjustment. If the bid is accepted the capacity holder will receive a separate energy compensation in addition to the capacity payment.

Regulating power market is maintained by Fingrid together with the other Nordic TSOs. In the regulating power market, production and consumption capacity owners can offer their adjustable capacity to the market. Balancing bids can be given for all resources that are able to implement a power change of 10 MW in 15 minutes (5 MW if electronic activation is possible). Bids are to be submitted to Fingrid no later than 45 minutes before the hour in question. Figure 13 shows the two types of balancing bids.

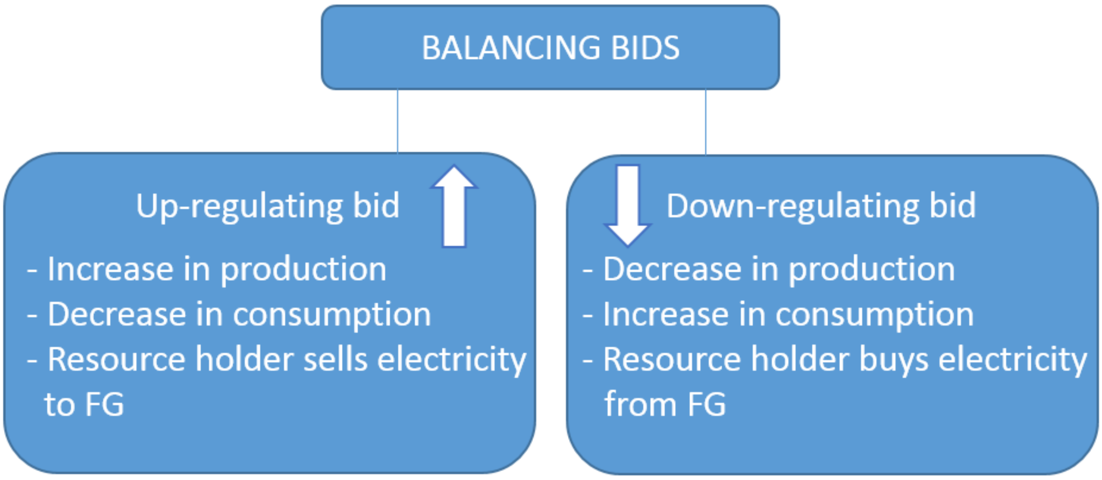

Figure 13 Up- and down-regulating bids explained (Fingrid 2017d)

Balancing bids have to contain the following information about the controllable capacity:

- power (MW)
- price (€/MWh)
- production/consumption
- transmission area where the offered resource is located
- name of resource, e.g. power plant, type of production etc.

All the balancing bids are used in the price order so that first is used the cheapest up-regulating bid and correspondingly the most expensive down-regulating bid. When the time limit for the submission of balancing bids is exceeded, the bids are formatted and used in price order, starting from the cheapest one. The last bid that is still needed for settling the imbalance sets the final price for all bids. Figure 14 shows the regulating power prices of one week in January 2014. (Fingrid 2017d)

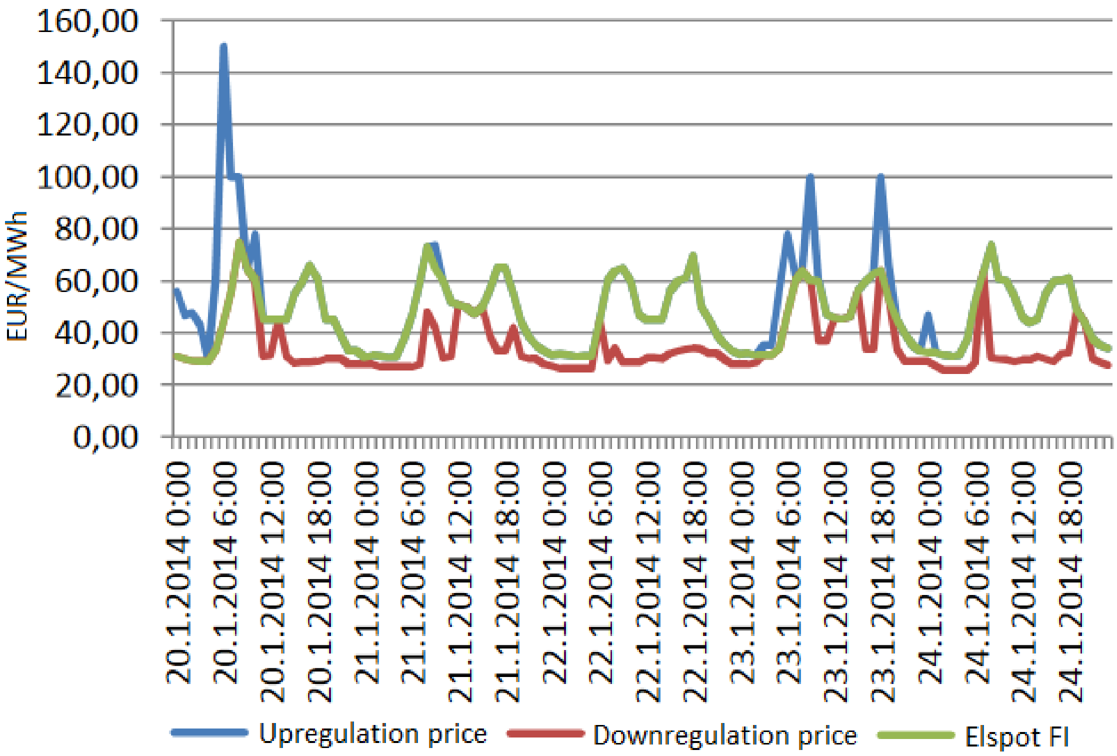

Figure 14 Up- and downregulation prices and Elspot FI regional price in January 2014 (Partanen et al. 2016)

As we can see from the figure above, regulating power price differed from the ElspotFI almost all the time, so the need for balancing actions was near permanent. Times when the need was for up-regulation can be seen from the figure as a blue curve above the green ElspotFI curve and times of down-regulation as a red curve beneath it. It is possible for down-regulation price to go to the negative side, which means that the need for down-regulation is so critical that the TSO is willing to pay consumers for consuming electricity. On the 7th of May, 2017, the down-regulation price was -1000 €/MWh for four hours. This was the lowest price ever for down-regulation in Finland. (Fingrid 2017h)

3.3 Inertia

In the electric system, also kinetic energy or in other words, inertia, is needed. Inertia is the resistance of any physical object to any change in its state of motion; this includes changes to its speed, direction, or state of rest. In the power system it is generated by rotating mass of the power plants and turbines. The inertia is required in cases of disturbances. If a power plant is disconnected from the network as a result of fault - only sufficient amount of rotating mass in other plants prevent a widespread power outage. Most of the inertia is generated in conventional power plants such as nuclear power plants but also in hydro and thermal power plants. Wind power produces only little inertia and solar power not at all. The increasing share of wind and solar power of the total production has brought a question of system security in Nordic electricity network. The power obtained from the wind power plant and the rotation speed of the wind turbine vary at random as the wind itself, and such power plants are often connected to a synchronous AC grid by rectification-inversion equipment. Without a synchronous connection the varying speed of wind turbines does not disturb the synchronous grid running at standard speed, but on the other hand, the benefit of the inertia supporting the AC grid frequency is lost. (Fingrid 2015)

Disconnection of a large power generator leads to a situation where the power system has more consumption than production. As a result, the loads of other synchronous generators in the network increase and their rotational speed is reduced. The frequency of the electrical system depends on the rotational speed of the synchronous generators. Thus, disconnection of a large production unit results in decrease of power grid frequency and the rate of change in frequency depends on the total amount of inertia in the system. Figure 15 shows the drop in frequency after a loss of production, with different amounts of kinetic energy in the system. (Fingrid 2012)

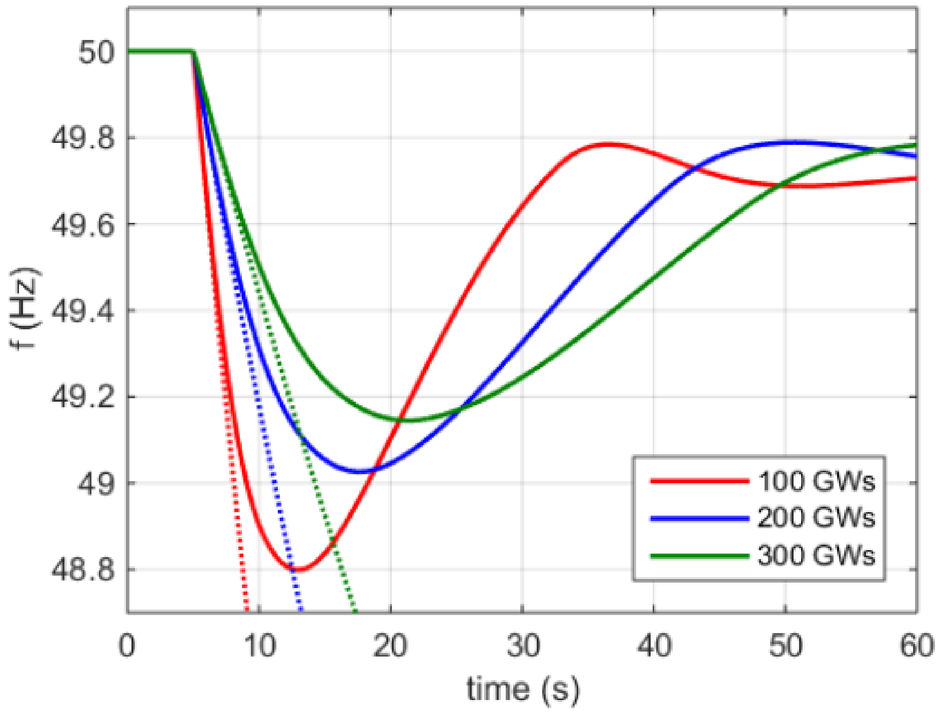

Figure 15 Amount of kinetic energy [i.e. GWs] in the power system determines the inital gradient of frequency drop after a loss of production (ENTSO-E 2013)

As it can be seen from Figure 15, the amount of kinetic energy determines the initial gradient of the frequency drop and for that reason the lack of it is especially critical in the first few seconds of disturbance. This is also the reason why the power reserves have to act so fast. (ENTSO-E 2010 & 2013)

3.4 Balance sheet management

Times of high demand can usually be predicted quite accurately as demand follows pretty much the same pattern every day. The volume of demand is also relatively predictable, as industrial consumers must provide forecasts of their own expected consumption to TSO, who is responsible of the national balance sheet of demand and supply. Even though forecasts of consumption are made as accurately as possible, it is still impossible to completely predict future consumption. In addition, weather forecasts are seldom precise and roughly a quarter of total energy consumption in Finland is weather-dependent in form of heating (Tilastokeskus 2017). That, combined with uncertainties in the power yield of renewables lead to a continuous need for balancing actions.

The Electricity Market Act requires that each party of the electricity market has to have agreements for electricity generation and procurement covering electricity consumption and supply at every hour. This balance responsibility is carried out so that each buyer and seller of electricity has an open supplier, which covers the difference between their predicted and actual use or production of electricity. The top level open supplier is the system operator, i.e. Fingrid in Finland. Those market players whose open supplier is the system operator, like UPM Energy, are called Balance Responsible Parties (BRP). Electricity trades typically have small margins and high risks, requiring systematic risk management by the parties involved. In electricity procurement and sales planning, prediction of consumption plays a key role. Forecasts are also used for the planning of electricity generation. Forecasts have improved through time, but usually there is still a deviation between production and consumption. The deviation of each major operator is treated as imbalance power. Deliveries of the parties to the electricity trading business are settled through balance statements. (Partanen et al. 2016)

Balance service is a transaction in electricity to compensate the imbalance between parties' actual deliveries and purchases. Balance service trade is conducted between the eSett's balance settlement unit and BRP. The three Nordic TSOs (i.e. Fingrid (Finland), Statnett (Norway) and Svenska Kraftnät (Sweden)) together own the eSett company that is providing imbalance settlement services to electricity market participants. The amount of imbalance power is determined in the balance settlement. Imbalance power is separately priced for production power and consumption power. (eSett 2017)

3.5 Summary

In Table 1 below, all the electricity market places are gathered. Elspot and Elbas markets are managed by Nordic TSOs through Nord Pool Spot and mFRR and FCR markets by Fingrid.

Table 1 Electricity market places

	Nord Pool Spot		Fingrid's reserves		
	Elspot	**Elbas**	**mFRR**	**FCR-D**	**FCR-N**
Minimum bid	0,1 MW	0,1 MW	10 / 5 MW	1 MW	0,1 MW
Required activation time	12 h	1 h	15 min	5 s / 50 % 30 s / 100 %, when *f* is 30 s under 49,5 Hz	3 min, when *f* deviates from 49,95 - 50,05 Hz
Activates	–	–	Based on the offers, several times a day	Few times a year	Constantly

Table 1 shows the minimum bid sizes, required activation times and activation frequencies of the different electricity markets. Minimum bid size for mFRR is basically 10 MW but if an electronic activation is used, then 5 MW is acceptable. FCR-D reserve also enables relay-connected loads to be used. For them, the activation must happen immediately if the frequency is 30 s ≤ 49,70 Hz or 5 s ≤ 49,50 Hz. (Fingrid 2017i)

4. DEMAND RESPONSE

Power system operating and planning can be challenging since production and consumption must be in balance at all times, capacity constraints in the network must be respected and bottlenecks immediately addressed. Adjustable capacity in the system is necessary in order to address critical situations when they arise. Controlling the power production side is becoming more difficult with the increasing amount of renewables in production pool and in the same time the amount of power generated by most adjustable ways is decreasing, Nordic TSOs see the use of flexible consumption as an essential part of the future power system. Demand Response is a way for consumers to help maintain the balance in electricity system, reduce their own electricity bill and gain profit. This chapter explains why Demand Response (DR) is necessary for the efficient functioning of the joint Nordic market, especially now when traditional and flexible ways of producing energy is being replaced by rigid ones. In this chapter, DR is defined and the prerequisites and restrictions of operation are explained. (Fingrid 2015)

Demand Response means shifting the use of electricity from hours of high demand and price to times where demand and price are lower. It can also mean that an electricity consumer changes its electricity consumption based on an input coming from some actor so that the actor and the consumer both benefit from the action. This case could be when the power grid frequency deviates enough from its rated value and TSO asks consumers to change their consumption. This change may mean reducing consumption during periods when there is more demand than supply in the market and the price of electricity exceeds consumers benefit from using electricity. (Fingrid 2017c, Nordel 2004, Rautiainen et al. 2015)

For DR to become more common, TemaNord (2014) lists two conditions that must be met in order for electricity markets to get more active DR providers. First is that there must be clear demand for flexibility and secondly DR must be able to compete with other flexibility resources (generation, grid investments and storage), i.e. the demand side must be able to deliver the valued characteristics of flexibility in a cost-efficient manner. (TemaNord 2014)

4.1 Demand Response in practice

Demand Response is not a new thing, although the scale has grown considerably and the significance is now greater than ever. Since electricity storing cannot yet be reasonably implemented, electricity production and consumption must continuously be in balance. This requires flexible capacity from both electricity production and consumption. In future, with planned heavy integration of renewables in the production pool and also decreasing amount of traditional condensing power are drivers towards wider use of demand response. Areas in the Nordic countries that are dominated by stored hydro power and large industry are abundant with daily flexibility. Whereas in areas with wind generation and household consumers, flexibility is needed in order to balance daily fluctuations especially in times of peak-load, when the transmission capacity from other areas might not be sufficient. (TemaNord 2014)

Kristensen (2005) state that activating DR more widely is the only way for the system to generate a scarcity rent for peak-load generators in the Nordic market, without compromising the security of the supply. In times of extreme scarcity of electricity, wide implementation of DR could be enough to maintain the balance between supply and demand and no forced load shedding would be needed. Disconnecting end users through DR will allocate the necessary compensation to the disconnected end users (Nordel 2004). Many industrial facilities in Finland have for years made trade with Fingrid concerning loads which can be disconnected. The loads would ideally be such that their temporary disconnection does not interfere with other plant production processes. (Fingrid 2015)

At present, electricity consumption does not correspond much with price excluding some loads of heavy industry. However, very large potential for actively participating in DR could be found in energy-intensive industry where there are many sub-processes where the consumption could be reduced or totally cut down. Energy-intensive industries, like forest or metal industries, can offer large units of flexible capacity, which is why this type of industry offers great potential for DR. (MEE 2014)

The Nordic countries have strong and working electrical interconnections enabling effective cross-border trade. This offers an opportunity for the cost-effective development of DR within the Nordic area. A simulation conducted in 2004 shows that DR in one region will have an effect on the prices of other regions too. In other words, price spikes can be eliminated from the whole trade area by active DR in one price region. Thus, all the regions are able to benefit from DR resources regardless where DR is activated. This situation corresponds generally, but there might be some special occasions where congestion and temporary constraints on the interconnections may limit the impact in other regions caused by DR in one. (Nordel 2004)

Regions with lot of wind power generation can secure with DR that all renewable energy is exploited. If the electricity production surpasses demand, then wind power generation may be needed to curtail if not enough DR is available. It is economically more viable to curtail wind power generation than nuclear or other conventional power generation, because of the rapid change that is possible with wind turbines. DR is a tool to deal with this issue, so that all possible clean energy could be harnessed. The actual potential of DR is dependable on several factors such as the frequency and duration of the response, the time available before response and the trade cycle of processes in industrial companies.

Loads which can often be found in any factory environment like electrical heating, ventilation and lighting also constitute a substantial potential, although the initial investment needed may be excessively large for the return expectations. (Nordel 2004, Farin et al. 2005)

End-user reactions will have direct effect on market equilibrium. In times of high demand, where the supply curve of the electricity market is almost vertical, even small changes in demand by DR can have huge impact on the market clearing price, see Figure 16 below. (Nordel 2004)

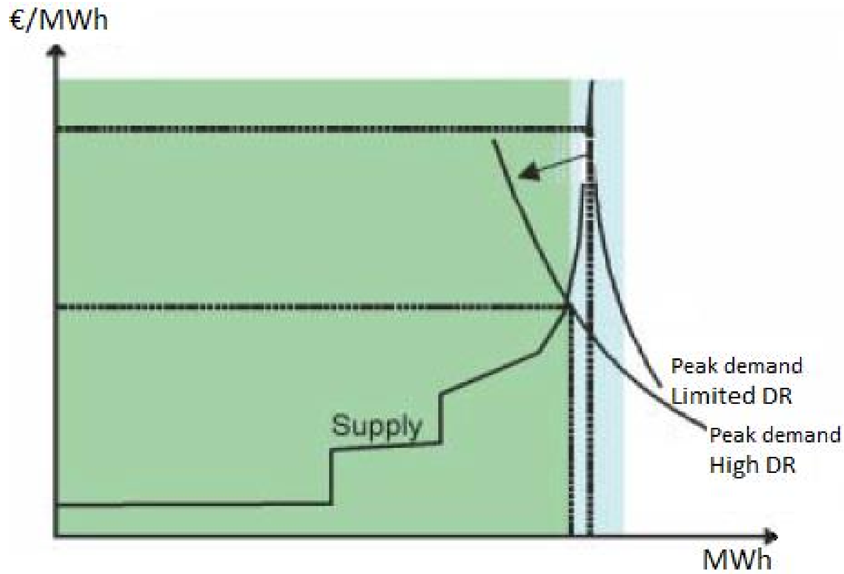

Figure 16 The effect of Demand Response on electricity prices (Nordel 2004)

Figure 16 shows the effect of DR on electricity prices. The price of electricity is in correlation with demand and therefore it is clear that increased DR will have reducing effect on price spikes by means of reduced demand.

4.2 Smart Grid

Electricity transmission in Finland is divided into distribution networks and nation-wide transmission grid, which both have a regional monopoly. Function of power grid is to transfer electrical energy from power plants to customers in safe, reliable and economical way and also to enable power generation economically. Basic electricity transmission technology has remained unchanged for decades and no breakthrough on that area is visible either. Although basic solutions in electricity transmission have not changed, technology development has made the use of power grid in a safer, reliable and more efficient manner possible. (ElFi 2017)

Smart Grid is a vague concept and has no official definition. It includes an idea of highly automated and monitored grid of which general property is flexibility; it adapts to every situation taking into account all available resources in the best possible way (Bollen

2011). Smart Grid is not only technology and equipment, it has to adapt to changing needs of electricity consumers and to become a working marketplace. Smart Grid is a service platform and an extensive functional entity. Smart Grid enables electricity users to participate more actively in the electricity market and DR. It also enables new kinds of electricity products and pricing models to be created. Electricity security and power balance management are getting more challenging with the heavy penetration of renewables and the geographical dispersion of production units. Increasing intelligence in power grid enables it to adapt to changing operating environments cost-effectively. Smart Grid also provides better tools for troubleshooting, proactive maintenance and clearing bottlenecks. Intelligent power system monitors the flow of electricity and continuously optimizes the consumption and production of electricity. It enables electricity to be produced and consumed wherever it is most cost-effective at the given time. (TEM 2017)

DR is an action aiming to improve the operation of the power grid. Because all the electricity generated has to be consumed at the same time every second, short-term response is required from the balancing resources and that requires a high level of automation. Efficient DR is dependent on equipment and technology that enable automatic processing and publishing of data and calculation of the most viable response. Network automation is advanced in Finland and we have been a forerunner in implementing smart meters and Automatic Meter Reading (AMR) systems. Smart meters are already in use practically in every household and also widely in industry. (TemaNord 2014)

4.2.1 Datahub

As a prerequisite for consumers to participate in DR is available and up-to-date price information. Especially in times of scarcity, real-time publishing of electricity prices is essential for actors to become interested in changing their electricity use. Real-time publishing also supports equal treatment of market players. In the present situation, some of the parties in the regulating power market get a view on the price level of the control power. At present, this information is not available for all regulating power market participants. View on the price level is created when the party's own bid is accepted in the market. Real-time price information enhances operators' ability to participate in DR and thus, supports the security of the electricity system. At the same time, it increases the opportunities for risk management in one's own business and improves the cost-effectiveness of balance management. (Fingrid 2017c)

Remote readable intelligent electricity meters, or Smart Meters, play an important role in managing the power balance. They provide a wide range of information about the operation of power grid. When practically every node in the power grid is equipped with meters continuously reading the variables like voltages and currents, it is possible to make use of this available data in real time through one centralized platform. Datahub is Fingrid's centralized information exchange system, primarily designed for the retail electricity market where data on smart meters will be stored. Fingrid began to design the Datahub in

2015 and it is scheduled to be fully operational in 2019. It is designed to accelerate, simplify, improve and enhance not only the operation of retail electricity market but also other electricity markets. It enables equal and real time access to all data even for a third party like an independent aggregator. One remarkable strength of the system that is managed by neutral operator, like the TSO, is impartiality. Similar models have already proved to be effective in Denmark and Norway. Datahub would certainly be a step forward for the wider implementation of DR. (Fingrid 2017c)

4.3 Participating in the reserve market

As a result of the changing electricity production structure, consumption will need to be more involved in balancing the difference between demand and supply. Fingrid, who is responsible for maintaining the power balance in Finland, manages a few different power reserves (see Chapter 3.2) for maintaining the balance. Providing flexible loads or production units for Fingrid's power reserves also provides a benefit opportunity for flexible capacity holders. Although there is an increasing need for maintaining power reserves, the technical requirements for participation have been constantly tightening. Fingrid sets high standards especially for the capacity operating as a reserve but also the capacity holder must meet some requirements. Especially the requirements for capacity participating in FCR exclude many seemingly suitable targets. (Fingrid 2017f)

Fingrid, who manages the power reserve markets in Finland, requires different agreements for participation depending on the market place. First of all, the reserve vendor must be the owner of the controllable target or at least a participant body in the open electricity supply chain (electricity vendor or a Balance Responsible Party - BRP). Adjustment features of automatic reserves must also be verified by a control test, so that the dynamics and stability of the target can be evaluated. (Fingrid 2017f)

In the FCR-D market, it has been possible to operate also as an independent third party aggregator since the beginning of 2017. The reserve vendor is responsible for the entire reserve service, but it may have an additional service provider that is in charge, for example, for making bids at the reserve market. A reserve target must meet the technical requirements of the reserve market. Flexible capacity targets of the same reserve vendor can also be aggregated so that the aggregated items meet the technical requirements and marketplace conditions as a whole, even if individual items do not meet them. Aggregation is allowed only of the same balance sheet of BRP, with the exception of the FCR-D market. More about aggregation in Chapter 5.2. (Fingrid 2017f)

4.4 Challenges with Demand Response

DR actions increase the overall power grid efficiency by shifting demand from peak load times to times of less demand. While this impact of DR actions is well-known, the overall energy conservation is less studied. The increase in energy use after a DR action might actually be bigger in some cases than the initial decrease during DR action. For example, if a household reduces its peak load time use of residential air conditioners during a hot summer day, the A/C unit might need to work harder afterwards to return the original temperature. (BetterEnergy 2015)

Industrial production processes impose restrictions on electricity consumption objects towards participating in Demand Response because even though some processes of a process entity could be used in a flexible manner, the other subprocesses might be disturbed. Implementing DR in industry is possible only when the load may be shifted in time or it has inertia, storage possibilities or excess capacity. An example of the inertia enabling DR is that the temperature in a building or in a process will not change instantly if the heating system is shut down, so it has one kind of inertia, which enables the implementation of DR. (TemaNord 2014)

Industrial production processes today are much more integrated entities than before. Therefore, changing the use of electricity in one factor may compromise the functioning of the whole process. Some processes are designed to run without operating interruptions. Listed below are some reasons why implementation of load control may be challenging or harmful. (Farin et al. 2005)

- Shutting down and restarting the process equipment may increase production costs, reduce the quality of the product and even lead to equipment damage. Moreover, in some cases safety risks are possible if the process includes dangerous elements such as explosive materials or toxic substances.
- Restarting process equipment may cause problems and it may lead to shut down of entire production line. The ramp-up of interrupted production line may take several hours. Startup situations almost always require close attention of staff in the vicinity of booting device.
- Shutting down process equipment during winter time may result in freeze damage, because often the heat produced by the device itself ceases.
- Process integration complicates the implementation of load control; stopping certain sub processes may stop at the same time the generation of heat or process gas used as a fuel for the power plant.
- Customer-dependent process. Process integration into the production of the customer without intermediate storage complicates the implementation of load control.

5. CASE STUDY OF FINDING FLEXIBLE CAPACITY IN INDUSTRIAL ENVIRONMENT

The aim of this work was to find capacity at UPM Rauma mill that could be used flexibly to create additional value in a way that paper production processes are not disturbed. In this study a flexible capacity is an electrical motor, a generator or a process that can be controlled in a way that serves more than one purpose. For example, filling a water tank can be scheduled in times of low demand, when the price of electricity is low while still ensuring the adequacy of water for the process needing it. A visualization of this is shown in Figure 17.

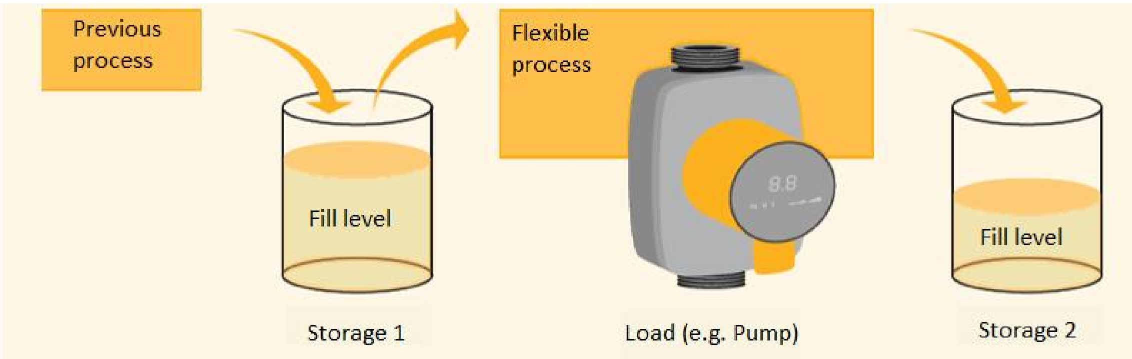

Figure 17 Flexible process or capacity can be detected for example if it has storages before and after (DENA 2017)

Storages before and after a load is a strong indication of potential flexibility because storages enable the use of the motor in limits of the fill level. In some cases, a process can be used in a flexible way even if it does not have storages, but usually a buffer is needed.

This chapter presents UPM Rauma mill and the main features it has. Also in this chapter, a method created and implemented during this study is presented. The method was developed to facilitate the identification of all the flexible capacity in an industrial environment and to guide them to the most suitable market. When implementing the method, it is essential to have good knowledge on both, the field of industry in hand and the potential markets in order to draw attention to right things.

5.1 UPM Rauma mill

Paper mills around the world are principally quite similar with each other. Even though the end-products can be quite different, the basics of paper making are the same in every mill. At least some basic processes can be found in every paper mill, for example, pulp production, actual paper making on paper machines and paper finishing like winding and wrapping. In addition, these processes are supported by many auxiliary functions such as ventilation, waste water treatment and possibly power generation. At Rauma mill, paper production begins from basics, meaning that freshly cut wood is brought there and the end result is that magazine paper rolls will leave it. Rauma mill includes three paper machines, grindery, wood yard, TMP plant, effluent plant and a power plant. In this work, ventilation is discussed separately as an additional function venue.

Refining and pulp blending are part of fibre processing. The objective of refining is to improve the bonding abilities of the fibres through separating them by mechanical stress. Pulp blending aims at optimal mixture for different paper grades. The fibre components and additive chemicals are dosed in the mixing tank according to the user-defined pulp proportions (receipt). After blending, the blended pulp is fed to paper machines.

The most common paper production process is based on wet web forming where the raw material components of paper are mixed with water forming a stock suspension. The suspension is then distributed to a thin wire through which water is removed by drainage. The rest of the water in web is removed by means of pressing and steam heating, resulting in dry paper. The paper machine can also consist parts like coaters, supercalenders and winders which all refine the paper towards specific end-product.

In addition to main components of paper making like debarking process, grinders and paper machines, there are many auxiliary functions that are necessary for making paper. Water for example is a vital component in the production of pulp and paper. Therefore it is crucial that the mill has an adequate supply of clean water. Water is used to transport heat, fibers and dissolved substances. Water is also used for cleaning and breaking down the fiber bonds. Heating, plumbing and air-conditioning functions (HPAC) and power production are also found from the mill area.

The consumption of heat and electrical energy in paper making varies depending on the end-product type. In this work, power consumption of electrical motors and processes was the main interest, so consumption of heat was not under the scope in this thesis. Power consumption of papermaking is largely influenced by highly intensive mechanical pulp production. Also the magnitude of production has linear dependency on electricity consumption.

5.2 Load aggregation methods

Operating on reserve markets requires relatively big amount of flexible capacity from the capacity owners. Given that the joint Nordic electricity system is as big as it is, the fluctuations in power can be significant. For securing reliable use, sufficient amount of flexible capacity is needed. Maintaining the adjustable reserve is considerably easier when the flexible units are bigger, because the amount of units then is smaller. It is more sensible for Fingrid to agree with a single operator for a 10 MW regulation than with ten operators for 1 MW each. That is why there is a minimum bid size for operation in these markets. Table 1 in Chapter 3.5 shows the minimum bids in each market

However, individual production and consumption units rarely possess as much flexible capacity as it would be needed to match the minimum requirement. Due to this, Fingrid's rules for participation allow combining, ergo aggregating, suitable capacity to be considered as a single entity that can be offered to the markets as a whole. This made it possible also in this study to capture the potential of much smaller units than it would be needed for a single bid in total. However, targets that are linked together in one bid should be somewhat similar to each other in order to easily control and monitor them.

Next, different ways to aggregate smaller units into larger entities are presented. All the means suggested are developed by the author and intended to serve a variety of industrial operating environments.

Custom 1: Location
All the targets of this block are located near each other. For example, the targets are all part of the Grindery, or they are connected to same electrical center.
Pros:

- Easy to control and monitor
- Under supervision of only one superintendent
- It is possible to connect multiple targets to a single control system

Cons:

- The targets may be of a very different type and the available start time and length of flexibility can vary greatly
- It may be difficult to find enough flexible capacity from a restricted area

Custom 2: Type
All the targets of same type aggregated into one block. For example, pumps or mixers.
Pros:

- Clarity – it is easy to find and form this kind of blocks
- Only one variable to be monitored, e.g. consistency or surface level

Cons:

- Targets may be physically distant from each other, so the impact of adjustment is on several processes
- Targets might need several monitors and control systems, which would increase the initial investments
- Targets may have varying flexible times

Custom 3: Duration of flexibility

Targets with the same flexibility features like the duration of flexibility into one entity.

Pros:

- Theoretically, the best possible way because a particular block should be provided to the markets for a certain amount of time

Cons:

- Would probably require multiple monitors and control systems
- It might be hard to find enough targets that could flex at the same time for a predetermined time
- The impact would be on several processes

Custom 4: Process

If a process as a whole could be flexible, then all the loads included could form a sufficient sized block.

Pros:

- Easy to monitor, control and manage
- Only one impact area

Cons:

- Flexibility often depends on the situation (queue)

Custom 5: Size (mixed model)

The goal is to form blocks of a certain size, for example, for a sudden power drop need.

Pros:

- Potentially includes only a few (1-5) large targets that do not interfere with a seldom adjustment
- Could be very flexible and easy to implement

Cons:

- It may be difficult to find such large and flexible units
- This would require very reliable system, because the impact of adjustment around these few targets would be notable.

5.3 Mapping the potential

The method created during this study consists of eight parts which all describe different stages of load identification in industrial environment. Finding and analyzing flexible loads is a key when assessing the DR potential of a unit. Figure 18 shows the implementation of the study as a flowchart. Below that, each step is explained in more detail.

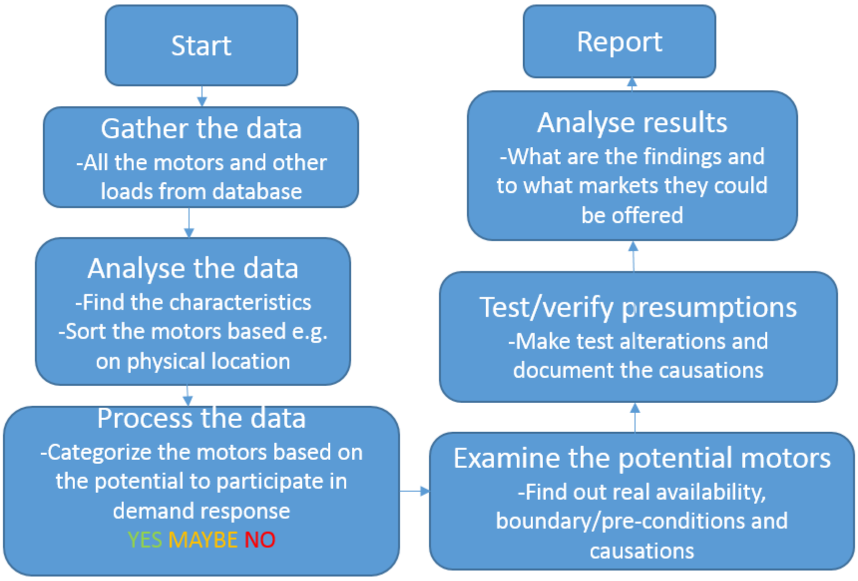

Figure 18 Developed method for mapping the DR potential in industrial environment

5.3.1 Start

The process of identifying flexible loads in industrial environment starts by exploring the operational environment. In this phase, it is important to recognize the staff that will be needed during the whole process in order to successfully carry out the task, such as superintendents, IT crew and automation plant technicians. This whole task involves so many areas of expertise that it is very likely that assistance will be needed.

5.3.2 Gathering the data

The actual work starts with gathering the needed data from database (e.g. SAP). This is very crucial part of the work because all loads are not necessarily in the same database and some information about the loads can only be found in some specific location. So it is essential to know exactly what information is needed and where they could be found during the whole process. When gathering the motor data, it is important to collect certain information that is needed on the motors to verify their competence to participate in certain markets.

At least the following data of each motor is essential: what is its function, nominal power, position in database, tag number, basic motor information and function venue. On the other hand, too much information can also make it difficult to handle the information. This data is then collected to a spreadsheet, for example to Excel, where the number of rows is equal to a number of motors, see Figure 19.

Position in database	Function	Function venue	Tag	Motor information	Power (kW)
Position 1	Pumps water from Container A to Container B	GRINDERY	12345677	MOTOR 1	100
Position 2	Container mixer	GRINDERY	12345678	MOTOR 2	75
Position 3	Grinding machine	GRINDERY	12345679	MOTOR 3	900

Figure 19 Illustration of Excel table showing information of motors

Figure 19 shows how the motor list acquired from database might look like. Information of each motor shown in the figure is important so that they can later be analyzed and found from both database and the factory.

5.3.3 Analyzing the data

When all the essential data is gathered it needs to be analyzed thoroughly. How many motors (rows in Excel) there is in total will be the most important fact when planning a schedule. Another important thing to note is how many venues does the research include. For example Grindery and Water Treatment Plant are totally different from each other and so it is advisable to familiarize yourself with the main features of each venue.

In this study the motors were first divided into nine Excel-tables based on nine different function venue. Each of the tables contain the motors of one venue so all the motors are only in their own table. In this phase it is also recommended to draw some illustrative charts from the data. It could be demonstrative to see as a chart, for example, how many motors there are in each venue or what is the percentage of over 100 kW motors. This kind of information could be easier to understand and analyze when presented as a chart, see Figure 20. The values in it are examples and do not represent the Rauma mill.

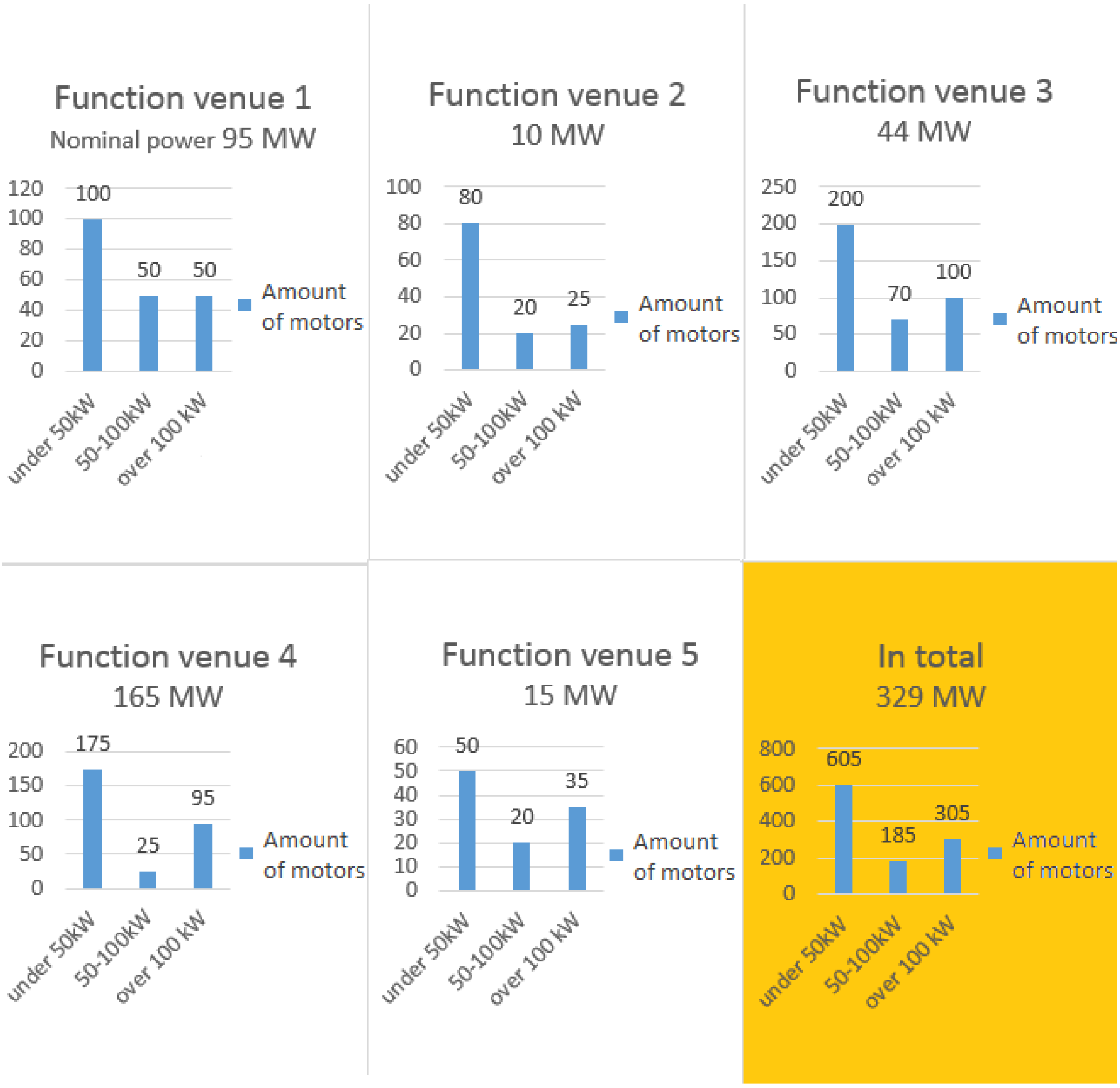

Figure 20 Motor data can be visualized to help on the analysis

Figure 20 shows the kind of graphs that could be illustrative in the first analysis of the factory. Each graph is named as their function venue and the last graph summarizes them all. As we can see from the figure, in this example Function venue 1 has 200 motors and nominal power of 95 MW in total. Motors are divided into three categories based on their nominal power and the amount of motors in each category is shown as a bar chart. With this kind of quick analysis, it is easy to see which function venues hold the most potential. In this set of examples, Function venue 4 would seem to hold the biggest potential because it has almost half of the nominal power of the whole factory and also has a third of all "over 100 kW" –motors. The bigger the motors are the bigger potential they usually hold because if one would need to find 1 MW of flexible capacity, it would require at least 10 motors of 100 kW or on the other hand 50 motors of 20 kW. However, the size is not the only thing that matters, the flexible potential is also up to the criticalness of the process or motor in question and so this kind of illustration is a good start but does not necessarily tell the whole truth.

5.3.4 Processing the data

Now when all the material is gathered the next step is to roughly estimate the flexibility of each motor. Execution of this step depends on available resources. If possible, the knowledge of superintendents should be used, because they are the professionals on their field and can easily spot the most potential ones. They can also detect the infeasible ones so they can be deleted before wasting too much time on them.

In this study a method is also developed to make the first filtration fast and efficient. The idea in it, is to sort the loads into three categories based on the initial estimate of the Demand Response potential. The three categories are visualized with different colors, see Figure 21. Each load is evaluated separately and the load-specific performance characteristics are written down in the same Excel table.

Position in database	Function	Function venue	Tag	Motor information	Power (kW)	Comment
Position 1	Pumps water from Container A to Container B	GRINDERY	12345677	MOTOR 1	100	Big stocks before and after
Position 2	Container mixer	GRINDERY	12345678	MOTOR 2	75	Could be possible to use 1h at lower power
Position 3	Grinding machine	GRINDERY	12345679	MOTOR 3	900	Critical part of paper making

Figure 21 Example of data procsessing. In this case, the motors are divided into three categories based on their Demand Response Potential

The colors used in this study are red, yellow and green. Red indicates that the load in question is not suitable for DR in any case. Green is the opposite, the load seems very potential for DR. Yellow includes the rest of the loads, they have potential to participate in DR but they have some restrictions or preconditions that have to be taken into account.

5.3.5 Examining the potential motors

When all the loads have been categorized and the reds have been extracted it is time to explore the potential loads more closely. During this study it became clear that almost every load had some preconditions to match before they could participate in Demand Response. These preconditions or restrictions were e.g. small size of the storage tank or critical processes close to a load in question. The ultimate precondition in this project was that the production of paper, which is the end product in UPM Rauma mill, was not to be disturbed. The effects of adjusting certain processes were carefully estimated due to this.

At this stage it is already necessary to know the markets that these loads could be offered to. Different operating reserves have different technical requirements and marketplace conditions (Fingrid 2017f). For Frequency Containment Reserve, the load must be able to react continuously to frequency deviations and having a frequency converter attached to a motor enables that kind of operation. The monetary compensation for capacity operating in FCR is substantial so evaluating the potential of every motor that have a frequency converter is worthwhile. (Fingrid 2017g)

All Fingrid's reserve holders are subject to providing hourly forecasts of the power consumption of the reserve. The forecasts are the only way to ensure afterwards that the reserve responded to the regulation commands. Forecasts should show the predicted power consumption of the reserve object for the offered hours as well as the available flexible capacity. The preparation of forecasts in a complex process environment is very challenging even for a short period of time. Predicting is based on the assumption of certain stability in the operating environment since changes in the operation of one process will have effect on surrounding processes too. When preparing forecasts, it is possible to exploit history data of motors to predict their behaviour in future. In order to analyze the history data efficiently, a tool in Excel was developed during this study. This tool is presented in chapter 5.3.7. At the Rauma mill, almost every motor under the scope had stored data of their previous operation. This data could also be presented as a trend, which can be used to analyze the operation of a motor quickly and thus determine its suitability for different DR markets.

Next, history data of four example motors is presented as trends. The motors are different in size and operation. After each example, an analysis is made of their suitability to different markets. The solid line represents the actual behaviour of the motor and the dashed lines in Figures 22 and 25 is the average drawn with Excel.

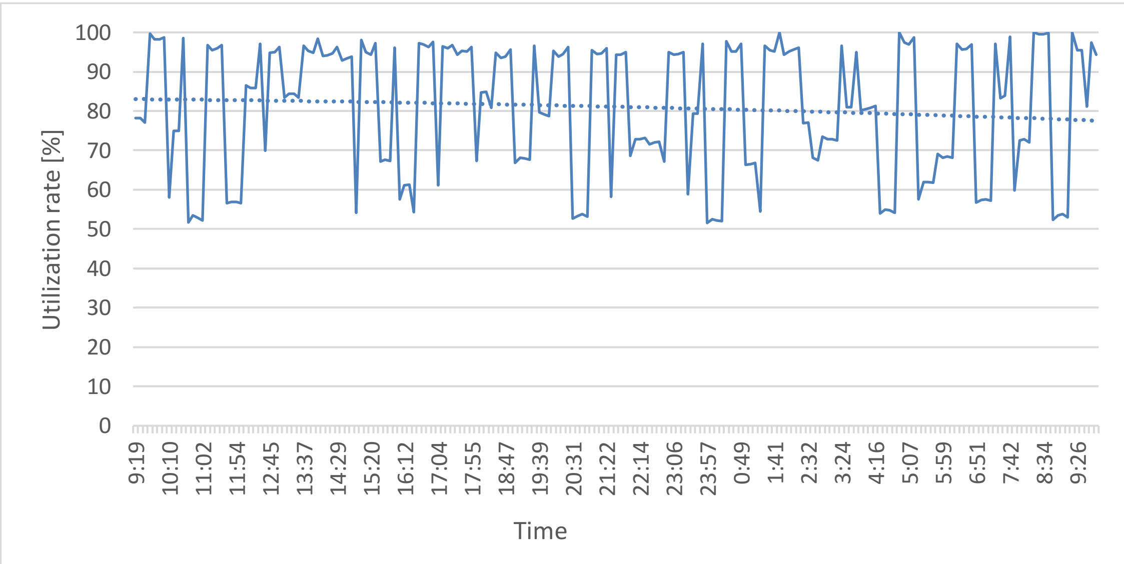

Figure 22 Utilization rate of Motor 1 from 24 hours

Figure 22 shows the utilization rate of the first example motor as a percentage of nominal power during 24 hours. From that figure we can see the motor running at 80 % in average but the power fluctuates irregularly between 50 and 100 %. This type of motor is not very optimal for the reserve market, but still suitable for example for up-regulation in regulating power market. If Motor 1 would contain a frequency converter, it could also be offered to FCR-D. The capacity that could be offered to reserve market in this case would be 50 % of the nominal power, assuming that the motor behaves in the future the same way as it does in the shown trend. Even though the average utilization rate of Motor 1 is about 80 %, only 50 % of the nominal power is available at all times.

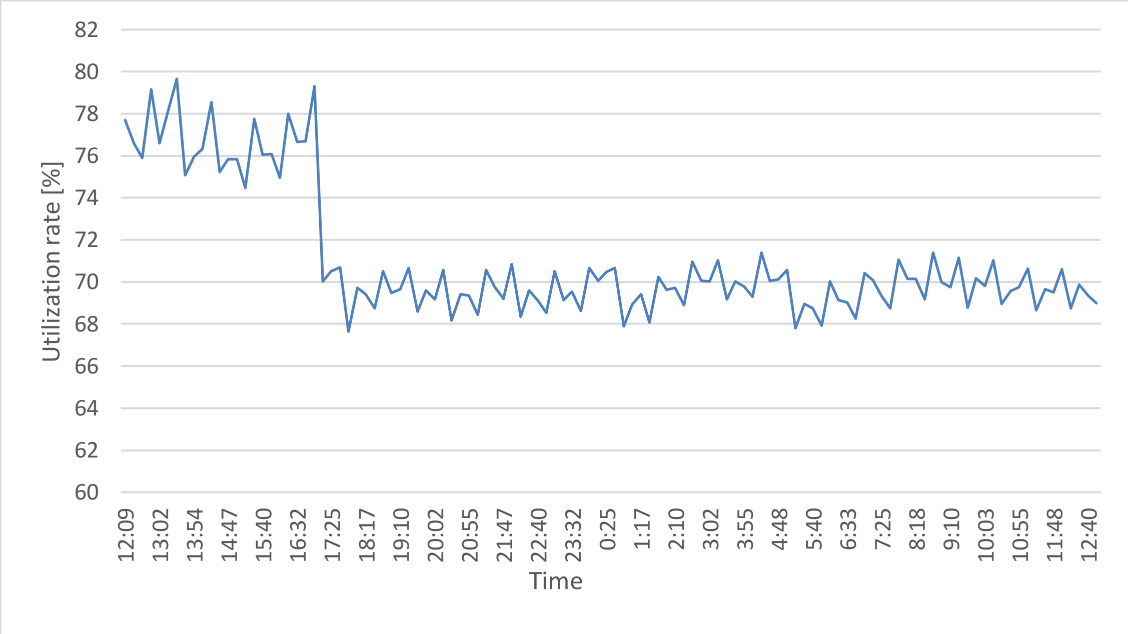

Figure 23 Utilization rate of Motor 2 from 24 hours

Figure 23 shows the history data of Motor 2 and the change in set value around 5 pm. This kind of bias can be detected in the behaviour of certain processes when the product type is changed in the production line. In cases like that, the power change is easy to predict and add to forecasts. However, if the power drop is manually adjusted, for example, due to the excessive heating of motor, it might be challenging to estimate in advance. But, if the bias is predictable, this kind of motor would be ideal for reserve market because the power deviation range is only about 4 %.

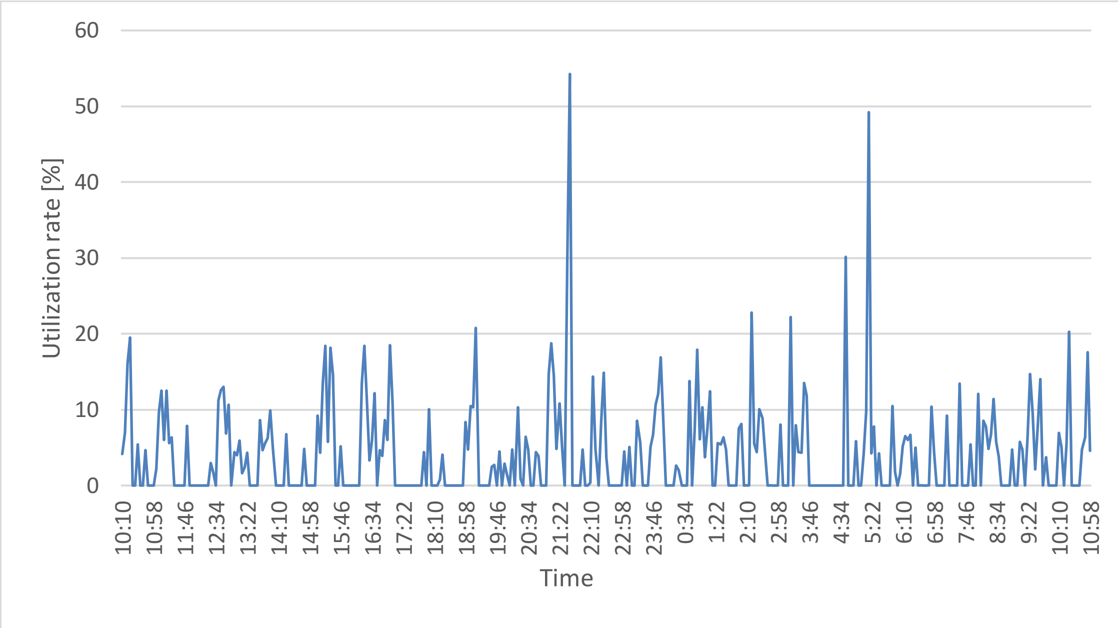

Figure 24 Utilization rate of Motor 3 from 24 hours

Third example, shown in Figure 24, is a typical pulper that can be found from paper mills. This is also an example of a motor that could easily be used in a flexible way due to low criticalness of this process, but due to its behaviour is not a good reserve target. From the figure above we can see that the motor is turned off at its basic state, but automatically turns on at the arrival of the pulp coming for pulpering. Depending on the mass of the pulp, its processing takes different amount of power, making prediction impossible. This type of motor could only be offered for down-regulation. The down-regulation capacity would be tested turning on the pulper without any mass to process, so the minimum capacity would be discovered.

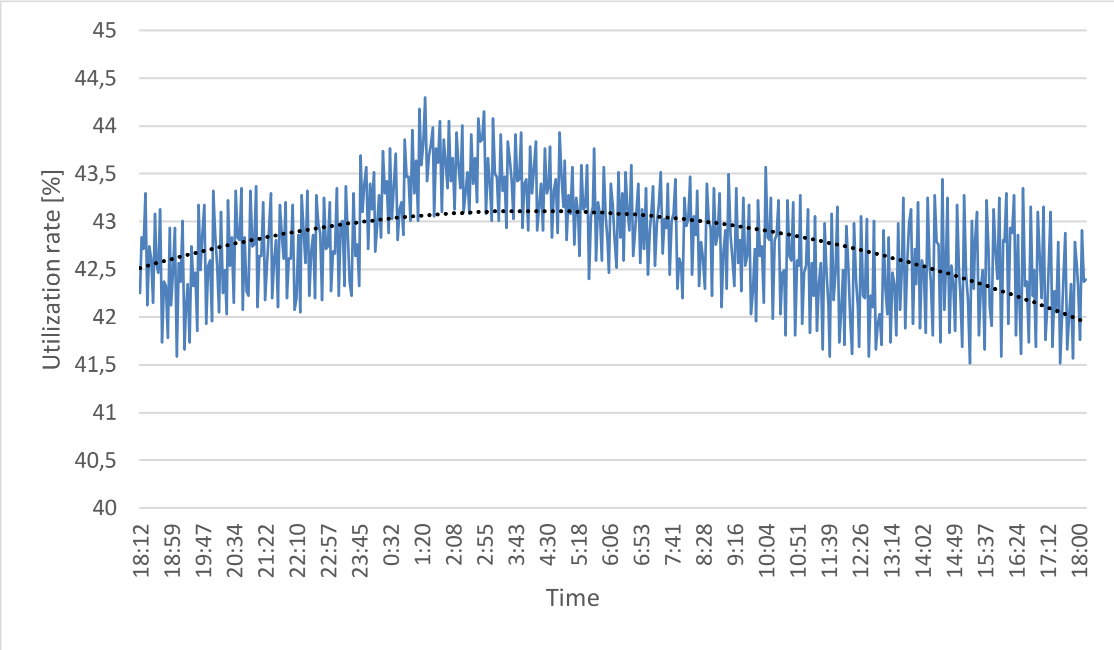

Figure 25 Utilization rate of Motor 4 from 24 hours

Motor 4, shown in Figure 25, is connected to a frequency converter, enabling it to be provided to FCR market. In the best scenario, the set value of the motor could be set to around 43 %, allowing it to fluctuate freely at ± 43 %, ergo between 0 and 86 %. Thus, the motor could be provided to the most profitable market, FCR-N, with a capacity of 43 % of the motor's nominal power. In practice, the capacity that could be offered is always smaller than the theoretical maximum, due to the limitations of the process itself and also the processes before and after.

5.3.6 Verifying presumptions

When all the motors are evaluated and their potential for DR is initially estimated, it is time to verify the made presumptions. It is impossible to know for sure in a complex process industry, what effects adjusting some motors might have for the entirety. A controlled and well-designed impact test is the only way to reveal real effects.

When making test adjustments it is essential that all critical variables are measured. Only a person with sufficient experience is able to estimate the impacts of certain adjustments and design the test so that the necessary information is obtained with minimal risk possible. The test should be done under normal circumstances and in a manner that mimics a real control command coming from, for example, Fingrid.

There are several things to test before loads can be offered to reserve market. Fingrid wants to be sure that the reserve it assembles is going to work as promised. The loads need to work as predicted or otherwise the benefits might turn into costs. It is essential with certain reserves that loads operating there act quickly to the steering signals. It is also essential that the recovery time is determined, so it is known when the load can participate again to reserve activity. Testing should also yield the following information: is the controlling possible to do automated and what indirect and what immediate effects the adjustments have for surrounding processes and ultimately for the quality of paper.

5.3.7 Analysing results

Now that all the necessary and available information is gathered, an analysis is in place. It might be advisable to separate loads that are ready to be utilized for markets from those that need investments or further investigations. Some of the targets could be suitable for their load profile but do not, for example, have sufficient power monitoring. Some might be suitable if they were connected to a frequency converter or had larger storages before and/or after. These restrictions could be overcome with an investment that would eventually pay back. Determining acceptable time horizon for the pay back is one essential factor when assessing the profitability of investments. This is considered more in chapter 6.

As a part of analysis, a program in Microsoft Excel was created, where one can easily determine the most suitable market for each target containing a frequency converter. For FCR-N market, the load has to have symmetric adjustment capacity, which means that it needs to have potential to be regulated the same amount in both directions – up and down. So in practice, if a load operates at 95 % of its nominal power, only 5 % (95 ± 5 %) of its nominal power can be offered to FCR-N market. The program takes historical utilization rate as an input and offers the most profitable market and the available capacity that can be offered to that market in each hour as an output. Figure 26 illustrates the output of the Excel program created.

Input for the Excel program is a time-power series where each moment in time is paired with the active power of the motor at that time. The program then handles each hour separately and finds the minimum, maximum and average active power of all hours. The unit of active power is not watts in the first four columns but utilization rate in percentage, where 100 % equals to the nominal power of the motor. The payment for operating in FCR-N is much better than that in FCR-D, but the capacity that can be offered to FCR-D is bigger if the load operates outside the utilization range of 34-66 %. In addition, the time deviation of FCR-N market is zero in the long run which means that it does not have any effect on surrounding processes or on the total energy consumption. Whereas on the FCR-D market, if the regulation is activated, it means you probably have to compensate the regulation in your own processes sooner or later. You might be able to do it when the electricity price is low, but perhaps not.

hour	min.	max.	average	limit	FCR-N	FCR-D	to which market:
0	26,3	59,6	38,6	26,3	28,9	44,5	FCR-N
1	29,3	61,8	40,7	29,3	32,3	42,0	FCR-N
2	31,3	44,9	39,3	31,3	34,5	60,6	FCR-N
3	26,8	50,9	37,7	26,8	29,5	54,1	FCR-N
4	26,4	52,9	37,6	26,4	29,0	51,9	FCR-N
5	26,3	71,0	50,6	26,3	29,0	31,9	FCR-N
6	26,5	46,7	38,3	26,5	29,1	58,7	FCR-N
7	26,3	52,0	35,2	26,3	28,9	52,8	FCR-N
8	26,7	50,7	34,6	26,7	29,4	54,2	FCR-N
9	26,4	44,6	32,6	26,4	29,1	60,9	FCR-N
10	26,5	59,7	37,6	26,5	29,1	44,3	FCR-N
11	26,8	45,9	35,7	26,8	29,5	59,5	FCR-N
12	26,5	50,7	35,8	26,5	29,1	54,2	FCR-N
13	34,0	50,6	38,4	34,0	37,4	54,3	FCR-N
14	26,3	66,1	36,0	26,3	29,0	37,3	FCR-N
15	26,4	64,6	36,0	26,4	29,0	38,9	FCR-N
16	26,9	64,4	37,9	26,9	29,6	39,2	FCR-N
17	26,4	70,7	47,0	26,4	29,1	32,2	FCR-N
18	34,8	66,4	45,0	33,6	36,9	36,9	FCR-N
19	26,7	64,8	41,3	26,7	29,4	38,8	FCR-N
20	27,9	52,9	41,0	27,9	30,7	51,8	FCR-N
21	26,8	48,6	35,9	26,8	29,5	56,6	FCR-N
22	26,4	62,6	41,2	26,4	29,1	41,2	FCR-N
23	34,0	50,9	39,1	34,0	37,4	54,0	FCR-N
					30,7	48,1	

Figure 26 Output of developed Excel tool for guiding flexible capacity to most profitable market

Figure 26 illustrates the output of the Excel tool that was created during this study to analyze the motor history data and guide it to the most profitable market. In this example, it seems that this particular motor could be offered to FCR-N with an average power of 30,7 kW. Capacity to FCR-D would be almost 20 kW larger but the compensation there is significantly smaller so it would be better to offer this capacity to FCR-N market. The values in Figure 26 are examples and do not represent the Rauma mill.

5.3.8 Finishing the study

When the research is otherwise done, it is reasonable to recap what answers the research was supposed to yield and what was really achieved. Should something still be investigated more closely or is everything clear now? It might also be in place to record the unexpected challenges and obstacles encountered during the research so something could be learned from those too. In this study, this kind of discussion is done in chapter 8.

6. ECONOMICAL ASSESSMENT

Before end-users become interested in participating in DR, the expected cost-benefit balance of DR must be in favor of DR. When the net benefit is positive, it is good economic sense to react. Economic benefit can be achieved from the electricity markets: Elspot, Elbas, regulating power market and power reserve market. In this thesis the focus is on the ladder two.

Demand Response offers a direct source of revenue to electricity consumers as well as unique benefits to the markets. In 2013, homeowners and businesses in USA earned over $2.2 billion in revenues from DR. In addition to the revenues released into the local economies (hospitals, schools, industries etc.), DR has reportedly reduced investments in grid infrastructure and power plants (SEDC 2014). DR makes the power system more reliable while also provides multiple environmental benefits. DR reduces the need for fossil fuel power plants, saves energy and helps integration of renewables onto the power grid by providing increased stability and management. (BetterEnergy 2015)

All in all, DR is a win-win situation where end-users get revenue, TSO saves investment costs in grid infrastructure and also environment benefits due to the reduced CO2 emissions. But even though it is a good option in all perspectives, economic benefit for the end-user is the driving force behind participating in DR. The technical potential will not be activated in the marketplace if it is not economically viable for end-users to react. (Nordel 2004)

In this chapter, the economical assessment of DR is made in general and for the papermaking industry in more specific. The assessment is done solely from the point of view of end-users, so the overall net benefit for all parties is not evaluated.

6.1 Earning models

Fingrid, as a TSO in Finland, is responsible for maintaining sufficient amount of power reserve to handle disturbances in the power grid. It collects bids from adjustable capacity holders in the electricity market and based on these bids, the compensation for acting as a reserve is created. A few simplified examples of earning models are presented below in the Fingrid's power reserve market. Examples are collected from Fingrid's website and the prices are averages of actual compensations in 2016 and in some cases 2017. (Fingrid 2017g)

Case 1: *A target that can be adjusted in both directions and several times per hour can participate, for example, in FCR-N.*

- 1 MW of FCR-N on annual market, 7000 h use with a price for 2017. Compensation for activated energy is not included in the calculations. Compensation for maintaining the reserve operational:
  - 1 MW * 13.0 €/MWh * 7 000 h = 91 000 €/year
- 1 MW of FCR-N on hourly market, with an activation level of 74 % of the total amount of hours (8760 h/year). Price is the average from the first three quarters of 2016. Compensation for activated energy is not included in the calculations *(see Chapter 6.2)*. Compensation for maintaining the reserve operational:
  - 1 MW * 23.1 €/MWh * 0.74 * 8760 h = 149 743 €/year

Case 2: *A target that can be adjusted quickly when the frequency falls below 49.9 Hz can participate in FCR-D. Activation occurs less frequently than in the case of FCR-N.*

- 1 MW of FCR-D on annual market, 7000 h use with a price for 2017. Compensation for activated energy is not included in the calculations. Compensation for maintaining the reserve operational:
  - 1 MW * 4.7 €/MWh * 7 000 h = 32 900 €/year
- 1 MW of FCR-D on hourly market, with an activation level of 30 % of the total amount of hours (8760 h/year). Price is the average from the first three quarters of 2016. Compensation for activated energy is not included in the calculations. Compensation for maintaining the reserve operational:
  - 1 MW * 5.3 €/MWh * 0.30 * 8760 h = 13 928 €/year

Case 3: *A target that can be adjusted within 15 minutes can participate, for example, in balancing power market. In there an operator can leave offers for hourly up- or down-regulation. Up-regulation means increasing production or reducing consumption. Correspondingly, down-regulation means reducing production or increasing consumption.*

- 10 MW up-regulation bid of 100 €/MWh for the balancing power market with an average price from 2016 of all accepted bids for over 100 €/MWh up-regulation (2 % of all 8760 h). The compensation will be based on the most expensive offer accepted, for this time the average price of over 100 €/MWh up-regulations has been 155 €/MWh.
  - 10 MW * 155 €/MWh * 0.02 * 8760 h = 320 204 €/year

6.2 Compensation for activated energy

Operating on the reserve or regulating power markets can lead to balance error, as it is very difficult to adjust the exact quantity required. In the regulating power market, the difference between the actual power change and the adjustments that are contracted is compensated with the operators' open supplier like in case of a normal imbalance. The price for that compensation is the regulating power price of the hour in question.

In case of FCR-N, energy compensation is paid separately for the error in balance sheet. Equation 1 can be used for calculating the reserve electricity in cases when the time deviation differs from zero (Fingrid 2017i).

$$Reserve\ electricity = \frac{\Sigma R \times \Delta t \times 50\ Hz}{3600\ s} \times k \quad (1)$$

$\sum R$ is the actual total volume of the FCR-N of all parties included in BRP's balance multiplied by 10 (frequency response). Frequency response can be calculated by means of the frequency change and the consequently obtained power change using equation 2. Δt is the time deviation in seconds for the hour in question. The correction coefficient (*k*=0,7) takes into account the effect of the dead band on the activated energy.

$$R = \frac{\Delta P}{\Delta f} \quad (2)$$

Frequency response *R* refers to the capability of the reserve unit to participate in automatic frequency regulation. Its magnitude is determined by the features of the reserve unit and by the settings of the controllers related to it. (Fingrid 2017i)

6.3 Cost-effectiveness of participating in the reserve market

Participating in DR market will require investments in some cases. Fingrid requires reliable power measurements of the capacity operating in the reserve market. Sufficient power measurements need to be verified before capacity can be accepted as a reserve. At the UPM Rauma mill, almost half of the motors had power monitoring in advance.

Predictable revenues are necessary for covering the initial investments that would be needed to adapt the system to meet the requirements of Fingrid. However, revenues on the reserve market are entirely dependent on the power system's need for balancing actions and on the supply of other operators on the reserve markets. Only way to ensure that your own bid is accepted is setting the price so low that it will automatically be accepted when the grid is in need of balancing. That is reasonable only for objects that can be used flexibly at any times. For objects more critical, the price of adjustment needs to be higher than the harm resulting the adjustment.

Some of the motors at the Rauma mill would be suitable for DR, if some investments were made. Investments would be needed in the control systems, power measurement equipment and to enable real-time data transfer between Fingrid and the reserve object. Investments in frequency converters would involve a high risk due to their expensive price but also a high earning potential in FCR markets. If they could be moved from someplace not so critical, it would probably be beneficial to do so.

If this work were to be expanded to include also other UPM factories, the profitability of the investments would increase. Expenditure on the control system could be thus divided to several factories, as the control system would be designed to manage flexible loads irrespective of their geographic location. Instead, investments in hardware are not duplicable but should be made as needed for each plant separately.

7. RESULTS

The objective of this thesis was to assess the Demand Response potential of UPM Rauma mill. During the work, all the electrical motors of the mill were evaluated and in each case an estimate of the potential flexibility was made. First, each motor was examined as an individual and if flexible potential was found – the possible effects of adjustments for the surrounding processes were further evaluated. The final objective was to find flexible capacity that could be used for Demand Response in power reserve markets, in a way that the production of paper would not be disturbed. This chapter presents the main results of the work and assesses their consequences.

First, the results are examined more broadly at function venue level, i.e. how much and what kind of potential was found at each venue. This information is important, as most paper mills have same function venues with similar processes. Utilization of results at other mills will be easier when first identifying similarities. Function venues at UPM Rauma mill were: Grindery, Wood handling, Paper machines 1,2&4, Power plant, TMP, HPAC and Water treatment plant.

After the first elimination round of non-flexible motors, the remaining potential was no longer examined at the level of function venue but separately as individuals. At this phase, the aim was to find the true flexible capacity of the motors and to find possible constraints that could prevent the offering of these motors to the target markets. At this stage, the allocation is done based on the target market. Motors, different in forms of availability and technical characteristic were easier to be examined based on the requirements of target markets, because the motor characteristics and market requirements are different from each other.

There were tens of motors at UPM Rauma mill that had available capacity that could be used in reserve markets if it were only up to its surrounding processes. But the market requirement of providing exact forecasts are so strict that it excluded many otherwise suitable motors. If the power consumption of a certain motor depends on several other processes and therefore has very varying power consumption, predicting the consumption of this type of motor or process is very challenging, if not impossible.

7.1 Grindery

The flexible capacity of Grindery was already extensively harnessed for DR. Some large units have already been used in DR market for several years. According to the preliminary estimate, Grindery still had good potential to participate more broadly in the DR market, because it produces mechanical pulp for paper machines and therefore has large stocks so that the paper machines will not run out of pulp material because that would interrupt the paper production. Sufficiency of mechanical pulp for paper machines continued to set the biggest constraint when the potential of Grindery was further investigated.

The potential of Grindery was examined with the superintendent of mechanical pulp production during some five hours. In the first round, all the electrical loads of Grindery were examined and divided into three groups according to the rule presented in chapter 5.3, from which the color red indicated the impossibility to participate in any kind of DR, yellow indicated that the load in question might be suitable for DR but has at least some constraints and green was a sign of good potential for DR. Some 30 % of the still unharnessed motors were such that they might be suitable for DR. It would still require some evaluation but potential was found.

7.2 Wood handling

Wood handling consists of timber receiving, debarking, sawing and chipping. Wood handling processes are potential DR targets because there are lots of big storages there. DR potential from wood handling can be divided into two process entities, which both consist of several sub-processes. In this thesis these entities are called as chip-process and log-process. This kind of division is in place, because both of these processes are separately integrated entities also in real life. If one makes alterations in one of the sub-processes of the two entities, it affects the whole entity. Both of these processes are also preceded by wood debarking and sawing processes that are defined as critical so they cannot be used in DR. Within the time frame of this work, there was no time to make test stoppages to these processes, what would be needed in order to find out the real consumptions of these processes.

7.3 Paper machines 1, 2 & 4

When exploring the DR potential of the mill, the ultimate precondition was that paper production was not to be disturbed. For this reason, paper machines and their immediate auxiliary processes were not a promising target. After closer look, some DR potential was found after all. The potential was formed out of process entities, just as in the case of Wood handling.

7.4 Power plant

The power plant at the Rauma mill site was also not tempting DR target in advance, as its functions had already been well optimized. Only some of the activities related to the reception of fuels and some fuel crushers contained subprocesses that could be flexible.

7.5 Thermo-mechanical pulp – TMP

Thermo-mechanical pulp (TMP) production includes a lot of tanks and pumps, which is why DR potential there was projected to be great. TMP as a function venue level is also the largest consumer of electricity in the whole Rauma mill. The pulp masses in TMP factory are transferred from one container to another, in which they are mixed with some substances, such as bleaches. Electric power is consumed in TMP factory in the transfer and distribution of masses and in mixing tanks. The storages theoretically enable a flexible use of the pumps if the surrounding processes are not disturbed of the fluctuations in the tank surface. Some processes are so sensitive that even a slight change in the mass flow can disturb the fluent operation.

7.6 Heating, plumbing and air-conditioning - HPAC

This function venue is not localized in any specific area, but includes all the HPAC subsystems of Rauma mill. Especially air conditioning contains a lot of flexible potential as it is not optimized that well. This resulted in a relatively big number of flexible motors in the air conditioning systems. Almost all ventilation subsystems could be used in DR, but it should be noted that this whole potential would probably not be able to be switched off at the same time, but somehow staggered. If the ventilation is too much adjusted, it could have effects even on the paper quality, which needs to be avoided to the last.

7.7 Water treatment plant

Water treatment plant consists of large pools and pumps that enable water purification of waters from both Rauma mill and city. Because of such large capacity, some flexible capacity was found. However, even though the water treatment plant had some subprocesses that consumed a lot of power and could be used in DR, the surrounding processes were not always so flexible. In cases like that, the process with the least flexible ability dimensioned the flexibility of the whole process.

7.8 Summary

In Figures 27 and 28, the maximum potential income for the capacity to FCR and mFRR markets is estimated with different price limits. The price limit means that the compensation of the regulation has to exceed that limit in order for the bid to be accepted to the regulation. For every price limit, the maximum income is then estimated and also the utilization rate is shown in the graph. Utilization rate in this means the percentage of hours in a year that the bid would be accepted in the regulation with specific price limit. This data is freely accessible to everyone on Fingrid’s web site.

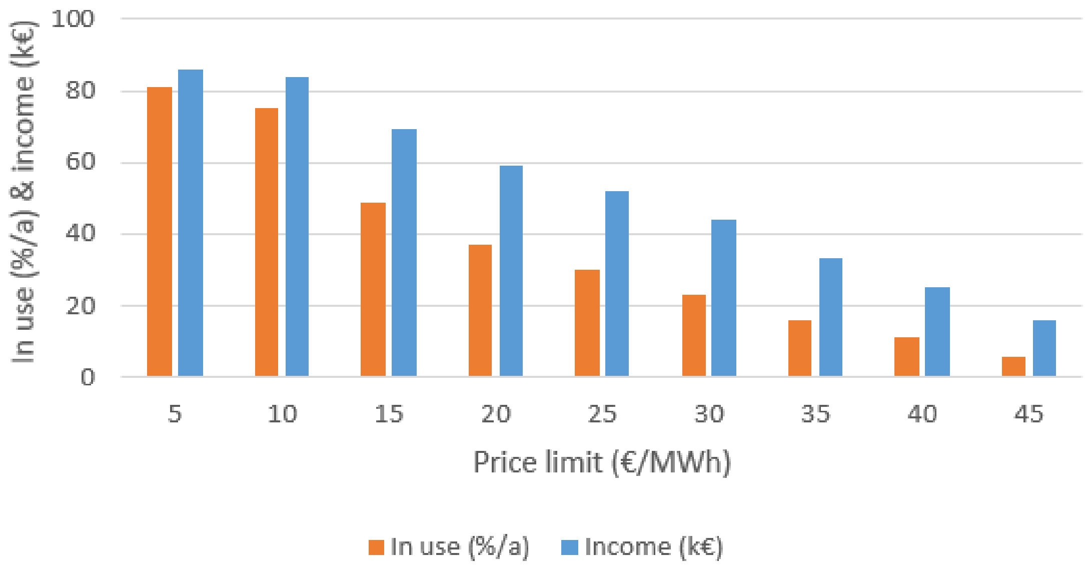

Figure 28 Maximum potential incomes of 0.5 MW from FCR-N market with varying price limits and utilization rates

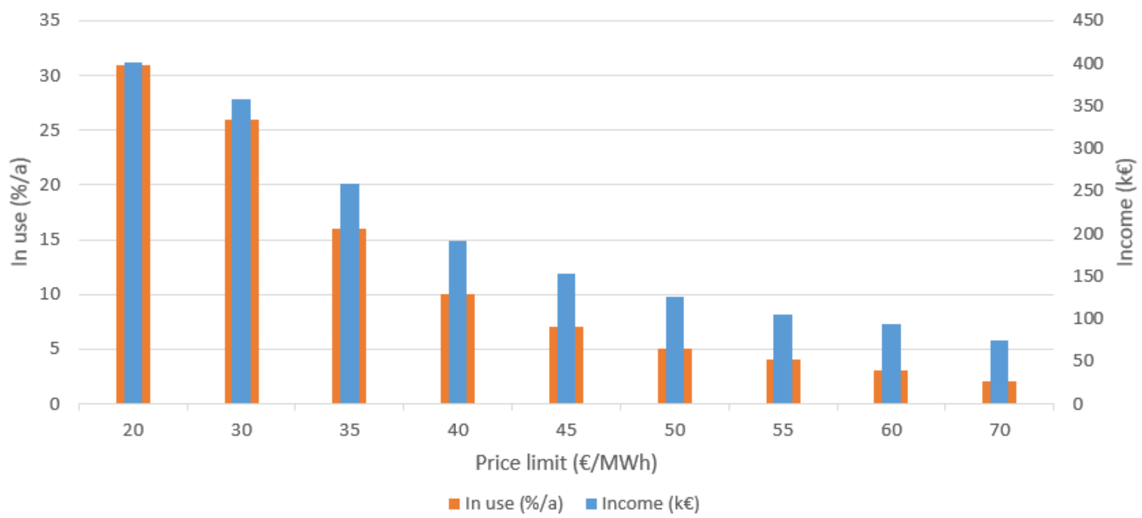

Figure 27 Maximum potential incomes of 5 MW from mFRR market with varying price limits and utilization rates

Figures 27 and 28 illustrate the potential incomes from two different target markets with a flexible capacity of 0.5 and 5 MW. The orange bar represents the utilization rate that would be needed in order to get the amount of income that the blue bar indicates with specific price limit. As we can see from the Figure 27, with the price limit of 10 €/MWh, the bid would have been accepted to regulation about 75 % of hours for the past year and the income from that regulation would have been 85 k€. Correspondently we can see from the Figure 28 that if the 5 MW of flexible capacity had been offered to mFRR market last year with a price limit of 30 €/MWh, the bid would have been accepted to regulation about 26 % of the hours and the income from that regulation would have been almost 360 k€.

8. DISCUSSION

During this master's thesis, the flexible capacity of UPM Rauma mill was thoroughly mapped. Every electrical motor in the mill area was examined separately and their potential to participate in DR was evaluated. The research was done to a point where the flexible capacity was found but not yet offered to any particular reserve market. The purpose of this chapter is to consider what is still needed in order to get the found potential operational in DR, what changes in the national energy field is expected and what effects these changes could have on the flexible capacity found in Rauma mill. Additionally, this chapter evaluates the author's performance during this work and whether the results corresponded to what was expected. Finally, the need for further studies on this topic is discussed.

8.1 Electricity market in the future

Electricity market is facing big changes when traditional and controllable ways to produce electricity is being replaced by rigid ones. The biggest driver behind this is the global pressure to reduce carbon dioxide emissions and also because the existing electricity production methods are based on exhaustible fossil fuels. Renewable sources of energy, such as wind and solar power are good for environment but pose new challenges in maintaining the necessary balance between production and consumption. Especially wind power is becoming more in common in Finland and in the rest of the joint Nordic power grid. That increases the need for power reserves because as it was pointed out in chapter 3, power yield from wind varies greatly and is very challenging to forecast.

If the controllability of the electricity production side is not considered to be sufficient at the national level, the control power in the future might come from new kind of hydropower plants where the water is pumped to upper pools when the electricity price is low and run through turbines when the price is high. The pump power plant has an efficiency of 70-80%. The key problem in building a pump power plant is the expensive price. Another solution for maintaining sufficient amount of regulation power is to improve the control capacity of the condensing power plants. Different ways to store energy such as batteries and compressed air are also potential future means for power control.

According to the current schedule, OL3 will finally start to produce nuclear power in 2018 (TVO 2017). This will reduce the need for import of electricity, which means that the cross-border power transmission is less frequently with the maximum capacity. This effect is still reinforced by the construction of new cross-border connections. As a result, a greater proportion of Finnish regulations can be implemented by Swedish and Norwegian hydropower plants. It must therefore be said that the need for DR in future depends on many factors, and national level energy policy will continue to have a major impact on that need. The reduction of balance settlement period from one hour to 15 minutes is also expected to lead to 15 minute products among the hourly and yearly products on the reserve markets. This may well add the willingness of some parties to participate in the previously impenetrable markets. Author's opinion is that due to all these future uncertainties and on the other hand, existing compensation levels on participating in DR, it would be wise to penetrate the reserve market now, when it is still possible without any major investments. Today, the compensation in DR is good and the demand for it is relatively great.

8.2 Assessment of own activity

Finding the mill's flexible capacity was a lot up to the mill staff, because the author himself did not have any experience on paper production. At times, the author encountered a lot of resistance to change. Some "old school" staff members were really skeptical about the possible benefits of DR and emphasized the potential harms of DR actions. Luckily, there were also people with more optimism. With the gained experience of the author, it could be said that the mill's flexible potential depends greatly on who you ask. All of the functions in the mill area are part of the paper making process and therefore necessary. However, not all subprocesses are critical at all times and due to the storages some can be used in a flexible manner. But one can have a different opinion of the criticalness of a certain process than the other. Many times, the author had to rely on someone's opinion due to the lack of own knowledge.

The rigidity of the information systems also hampered the progress of the work. The motor data was clustered in five different information systems and the location of certain motors was a mystery at times. Only a couple of people in the whole mill really knew the systems as a whole and an essential part of starting the work was finding them.

In this study, scheduling of the work was challenging especially at the beginning of the work because this had not been done before and also because the goals lived throughout the work. Valuable experience was gained from this work, both for scheduling and for mapping the DR potential in general. In the future, if studies like this are done elsewhere, this study is of great aid on implementing a similar research much more efficiently.

8.3 Future works

This research suggests that some types of industries have a significant DR potential. For example, all industries handling liquids have potential to participate in DR due to the storages these liquids need. Such industries include wastewater treatment plants and chemical industry. Based on the results of this work, also paper-making industry still has unharnessed potential to be utilized in the reserve markets. Especially in the pulp production there is a huge amount of flexible capacity, of which some is still yet to be utilized in Rauma mill.

9. CONCLUSIONS

The reliable functioning of the electrical system is based on the balance between electricity production and consumption. The power balance in Finland is maintained by the Transmission System Operator – Fingrid. Fingrid maintains the grid frequency at the rated level by ensuring that same amount of electricity is consumed at the same time that it is produced. If the balance is lost, there is a risk of equipment becoming broken and even a widespread power outages are possible. The occurring balance between production and consumption is reflected in the grid frequency and it is the same for the whole joint Nordic power system. The rated grid frequency, 50 Hz, occurs when there is perfect balance between production and consumption. If the production exceeds the consumption, the frequency increases and if there is more consumption, the grid frequency will fall. In normal operating state, the frequency is allowed to vary between 49.9 and 50.1 Hz.

The widespread introduction of wind and solar power production has hampered the frequency control of the power system. Such power plants generate electricity only when it winds or shines – not necessarily when there is demand for electricity. In addition, the number of power plants capable of regulating their power output at a low cost has decreased. This all has led to a situation where the electricity production side has lost its controllability. Demand side management, i.e. Demand Response, is one solution to maintain the required amount of controllability in the power system.

In order to maintain the balance between power production and consumption with lots of weather dependent production, there needs to be active and well-functioning electricity market that enables network balancing on a market-based basis. Operators with flexible capacity can provide their capacity to the reserve market to help maintain the grid frequency at rated level. Basically all kinds of production and consumption units can operate as reserves, but in practice there are some preconditions that the units have to match. For example, unit acting as a frequency controlled reserve needs to have a frequency converter in order to response changes in grid frequency in real-time. Generally, hydro power plants which can be run flexibly and agile, operate as frequency controlled reserves in the production side.

Fingrid has reserves for the normal state and for the cases of disturbances. Reserves that are used in normal state balance the unavoidable differences between production and consumption. Even though forecasts are made of future production and consumption, it is still impossible to avoid imbalance in whole. Reserves for disturbances are meant to answer quickly when, for example, a production unit suddenly disconnects from the network. Reserves can also be divided in manual and automatic ones. Automatic reserves activate when the grid frequency deviates enough from the rated. Manual reserves are activated by Fingrid if automatic reserves are not sufficient. The parties participating in the reserve market offer their flexible capacity as bids to Fingrid. The bidding determines at what price certain operators are ready to offer their capacity to Fingrid. Fingrid then uses the offers starting from the cheapest one. The last offer that is still accepted determines the compensation for all participants.

Demand Response has many advantages. It offers a variety of environmental benefits, such as reducing energy usage, offsetting the need for fossil-fueled power plants, and helping to manage system challenges from increased wind and solar energy. It can also be used to mitigate bottlenecks in the power system during peak-loads and thus reduces the price volatility and the need for new investments in grid infrastructure. With Demand Response, consumers can also save money by shifting some consumption from times of high electricity prices to times of lower price.

In Finnish forest industry large machines like grinders and refiners that are used in mechanical pulp production are already widely used in DR. Flexible capacity of one unit may not be significant but usually paper mills have several units which form a large flexible capacity combined. Mechanical pulp production is a good candidate for DR because the production can be regulated through intermediate stocks. Electricity consumption objects in municipal and industrial wastewater treatment plants also have good potential to act as a demand flexibility capacity. Adjustability of compressors and pumps used in wastewater treatment plants need to be at high level to accomplish the treatment of wastewater, which is why these items have the potential to be used as frequency controlled reserves.

The purpose of this work was to map out the potential of UPM Rauma mill to participate more extensively in Demand Response so that the production of paper is not disturbed. During the course of this work, a method was developed for mapping the potential and analyzing the results, which can be used also in a different industrial environment. The method for finding the potential consists of eight steps, that guide you through the process. During this study, also a tool in Excel was created to analyze the real potential of found motors. The Excel tool takes motor's historical data as an input and calculates the flexible potential for each market. With the tool, it is possible to estimate the monetary benefits that the capacity would yield in different markets.

The goal was to create a method that could be used to find out the remaining potential from Rauma mill and also from other UPM paper mills. The primary goal was to find capacity that could be offered in Frequency Controlled Reserve for Normal state (FCR-N). That was, because currently Fingrid has no such capacity from the consumption side and thus it would give UPM a pioneer status and valuable experience.

During the study, it was found that it is important to be able to transparently describe and discuss the possible changes that may occur in the development of operating models for enabling DR. This way, everyone knows what is going on and that helps on the motivation. The process of finding the flexible capacity depends a lot on the help of the staff, because they are the only ones that know what effects some adjustments might have. After some initial challenges, potential was found in plenty. Particularly in pulp production and in the water treatment plant, a lot of potential was found.

During the summer this study was made, the flexible capacity of the Rauma plant was not yet utilized in the reserve market because individual constraints of the potential loads was not fully reviewed. Additionally, access to the market would need testing also from Fingrid to ensure the required technical performance.

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