TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

EVELIINA SEPPÄLÄ

PRICING OF POWER SYSTEM BALANCING RESOURCES AND IMBALANCES IN SCARCITY SITUATIONS

Master of Science Thesis

Examiner: prof. Pertti Järventausta
Examiner and topic approved on 1 February 2017

ABSTRACT

EVELIINA SEPPÄLÄ: Pricing of Power System Balancing Resources and Imbalances in Scarcity Situations
Tampere University of Technology
Master of Science Thesis, 65 pages
August 2017
Master's Degree Program in Electrical Engineering
Major: Alternative Electric Energy Technology
Examiner: Professor Pertti Järventausta

Keywords: scarcity, scarcity pricing, regulating market, imbalance settlement, imbalance power pricing, reserves

One goal of European Union energy politics is to reach a leadership in use of renewable energies. Integrating the weather variable renewable energy in to the present power system requires also flexible resources that are able to balance the production and consumption of power system also in those situations, when weather conditions are not optimal for weather variable energy sources. In system which is based on market principles, the value of flexibility should be reflected in prices that result from balancing needs. Especially in cases, where there is a shortage of flexible resources, the price should reflect this scarcity.

This thesis surveys, what is meant by scarcity pricing in context of electricity markets and how scarcity pricing could be applied into regulating and imbalance prices in Finland. A look is taken into formation of regulating and imbalance prices in situations, when there is scarcity with the resources that can implement the up-regulation, meaning the regulation that either increases production or decreases consumption. Aim is to find out the mechanisms in present price forming model that prevent the price rise to reflect the value that consumers give for the scarce resource and also propose possible improvements in price formation and discuss the possible impacts of these proposed improvements.

The scarcity situation occurs in real-time, when the availability of resources for regulating are low compared to the need for regulating. Surveying the usage of bids that were given to Fingrid's regulating market during the time interval of 2013 – 2016, there was altogether 18 hours, when 90 % or more of the voluntary bids given by market participants were used. About two of third cases were associated with unplanned unavailability of either production plant or interconnector. Because of the principles of price formatting in cases with network interruption, the cases when there was a loss of interconnection, the regulating and imbalance prices both stayed low being about level of spot-price of the same hour. In these cases called special regulation, the price does not give signal of scarce resources. In other cases the price rose clearly over the average price of years 2013 – 2016. The highest price hit was 3000 €/MWh.

In this thesis also the possible implementation of scarcity adder in cases, when transmission system operator needs to use reserve that is meant to keep the power system to stand disturbances is discussed. The scarcity adder would bring the market participants incentive to participate in to the system balancing, which again can bring new business opportunities. The scarcity adder applied to the imbalance price would also allocate the costs of these reserves better to those participants who are creating the need for these reserves.

TIIVISTELMÄ

EVELIINA SEPPÄLÄ: Säätö- ja tasesähkön hinnoittelu niukkuustilanteissa
Tampereen teknillinen yliopisto
Diplomityö, 65 sivua
Elokuu 2017
Sähkötekniikan diplomi-insinöörin tutkinto-ohjelma
Pääaine: Vaihtoehtoiset sähköenergiateknologiat
Tarkastaja: professori Pertti Järventausta

Avainsanat: niukkuus, niukkuushinnoittelu, säätösähkömarkkinat, taseselvitys, tasesähkön hinnoittelu, reservit

Euroopan unionin energiapolitiikan tavoitteena on olla globaali tiennäyttäjä uusiutuvien energiamuotojen käyttöönotossa. Uusiutuvan, sään mukaan vaihtelevan tuotannon integroiminen sähköjärjestelmään vaatii kuitenkin rinnalleen joustavuutta, joka pystyy tasapainottamaan sähköjärjestelmän nopeasti myös niissä tilanteissa, joissa sään mukana vaihteleva tuotanto ei pysty tarjoamaan säätövoimaa. Markkinaperustaisessa järjestelmässä joustavuuden arvon tulisi näkyä hinnassa, joka säätöresursseista maksetaan. Erityisesti tilanteissa, joissa joustavat säätöresurssit ovat niukat tulisi hinnan heijastaa resurssin niukkuutta.

Tässä diplomityössä selvitetään, mitä sähkömarkkinoilla tarkoitetaan niukkuushinnoittelulla sekä kuinka niukkuushinnoittelua voitaisiin soveltaa Suomen säätö- ja tasesähkön hinnoittelussa. Työssä tutkitaan säätö- ja tasesähkön hinnanmuodostusta tilanteissa, joissa ylössäädön toteuttavista säätösähkömarkkinatarjouksista on ollut niukkuutta. Tarkoituksena on selvittää, mitkä tekijät nykyisessä säätö- ja tasesähkön hinnoittelumallissa estävät hinnan kohoamista kuvaamaan niukan resurssin arvoa sekä antaa mahdollisia parannusehdotuksia säätö- ja tasesähkön hinnoittelun kehittämiseen sekä kuvata näiden ehdotusten mahdollisia vaikutuksia.

Työssä tutkittiin markkinatoimijoiden Fingridin säätösähkölistalle antamien ylössäätötarjouksien käyttöä vuosien 2013-2016 ajalta. Tältä ajalta löytyi yhteensä 18 tuntia, joissa yli 90 % Suomen säätösähkölistan markkinaehtoisista tarjouksista oli käytetty. Noin kahteen kolmasosaan tapauksista voitiin liittää joko rajayhteyden tai tuotannon häiriö. Johtuen hinnanmuodostuksen periaatteista rajayhteyshäiriöistä johtuvissa tilanteissa kyseisien tuntien säätö- ja tasesähkön hinnat jäivät alhaisiksi pysyen kyseisen tunnin päivän sisäisen markkinahinnan tasolla. Näiden tilanteiden hinnat eivät siis anna hintasignaalia niukkuudesta markkinatoimijoille. Muissa tilanteissa hinta kohosi selvästi yli säätösähköhinnan vuosien 2013-2016 keskiarvon, korkeimman säätöhinnan ollessa 3000 €/MWh.

Työssä selvitetään myös niukkuuslisän soveltamista säätö- ja tasesähkön hintaan niissä tilanteissa, kun järjestelmävastaava joutuu käyttämään reserviä, joka on varattu varmistamaan, että järjestelmä kestää mitoittavan vian. Niukkuuslisän soveltaminen toisi markkinatoimijoille kannusteen osallistua järjestelmän tasapainottamiseen niukkuustilanteissa, mikä voi avata uusia liiketoimintamahdollisuuksia. Toisaalta niukkuuslisän käyttöönotto kohdentaisi reservien kustannuksia selkeämmin niille tahoille, jotka reservien tarpeen ovat aiheuttaneet.

PREFACE

This thesis was written in Market Design unit of Fingrid Oyj. I want to thank my supervisor M.Sc Mikko Heikkilä from Fingrid Oyj for discussions and guidance through this process as well as my examiner Professor Pertti Järventausta from Tampere University of Technology for constructive comments and interest towards this topic.

I want to also thank Satu Viljainen, Vesa Vänskä and Jyrki Uusitalo from Fingrid Oyj for providing their knowledge regarding the topic. Big thanks belongs also to the Jyri Ruotsalainen and Arttu Laapotti from Fingrid Oyj, who both dedicated their time and knowledge to help me with the data used in this thesis.

I am also thankful for my family for supporting me through my study years. Special thanks to J-P for all the love and support. Thank you also for all my dear friends near and far who have had a great influence in my life. I am also thankful for all the great people in Fingrid Oyj for encouraging working atmosphere.

Helsinki August 1st, 2017

Eveliina Seppälä

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LIST OF SYMBOLS AND ABBREVIATIONS

ACER	Agency for the Cooperation of Energy Regulators
aFRR	Automatic Frequency Restoration Reserve
BRP	Balance Responsible Party
BSP	Balance Service Provides
ENTSO-E	European Networks of Transmission System Operators’
FCR-D	Frequency Containment Reserves for Disturbance
FCR-N	Frequency Containment Reserves for Normal operation
LOLP	Loss of Load Probability
mFRR	Manual Frequency Restoration Reserve
MGA	Metering Grid Area
TSO	Transmission System Operator
UMM	Urgent Market Message,
VoLL	Value of Lost Load
SOA	System Operator Agreement

p	market price
q	quantity of product purchased with the market price

1. INTRODUCTION

1.1 The motivation and background

The electricity markets are in the middle of major changes due to large penetration of renewable energy in the future energy system. Decarbonizing the energy system does not only bring new opportunities for market participants but also plenty of challenges to be settled from the security of supply perspective. Predictability of renewable generation is full of uncertainties which bring challenges for system operator with responsibility of balancing the supply and demand. At the same time, when flexible balancing power is needed to pave the way for renewables, the running hours of conventional electricity generation has reduced and the low marginal costs and state subsidies of renewable energy has led to reduced incomes in wholesale markets, which has resulted in flexibility providing conventional generation exiting the markets.

The current situation in markets do not provide incentives for new generation investments nor for demand response and might lead running already existing power plants unprofitable. This can lead to the decrease of crucial balancing capacity, which is needed to react to the real-time imbalances in the power system. In order to enable the transition to decarbonized system without compromising the security of supply, the current electricity market design needs recasting and in order to secure the sufficient resources for real-time balancing, recasting the balancing market design is in a key role.

Electricity price plays an important role in market design. Pricing should give right signals to market participants as well as provide incentives to invest in solutions needed. According to economic principles, rising scarcity in resource should result in rising prices until the prices go beyond the demand side willingness to pay and this applies to all stages of different markets. Especially the price should reflect the scarcity and consumers' willingness to pay in situation when balancing resources are getting short and a risk of involuntary interruptions raises. At the moment, different mechanisms like and capped prices, lack of liquidity and pre-contracted reserves might prevent the energy price to reflect the real value of balancing energy during scarcity situations. This leads to lack of appropriate price signals for investors and demand response even in the future the need of flexible assets for balancing is expected to be increased.

This concern of lack of appropriate price signals is shared in many recent publications e.g. in (ACER/CEER 2016; IEA 2016). In these papers the term "scarcity pricing" is often offered as a solution to strengthen the market based approach to solve the problem and avoid the implementation of costly capacity mechanisms. However, term scarcity pricing itself is not unambiguous and can refer to different measures applied under scarcity situation.

In November 2016 European Commission published a Clean Energy Package, which is a commission's propose for rules that are needed to guide European Union through the clean energy transition that is changing the energy markets. Package includes also a proposal for a revised regulation regarding the internal market for electricity, where scarcity pricing is seen as one of the key issues enabling the appropriate investment signals for flexible assets (European Commission 2016). In the Clean Energy Package the scarcity pricing can be interpret as something that naturally happens, when all distortions, in particular price caps are removed to let the free formation of prices happen according to demand and supply. However for example report by Agency for the Cooperation of Energy Regulators (ACER) expresses doubts if the removal of price caps is enough to enable prices high enough to reflect the value what society place for a continuous electricity supply and if the costs of balancing resources would really be recovered. As one alternative option to further scarcity pricing report discusses about options of improving the design of balancing markets and by allocating balancing procurement costs to balance responsible parties in relation to their imbalances (ACER/CEER 2016). This means also recasting the formation of balancing and imbalance prices in scarcity situations.

1.2 Objective and content of the thesis

This thesis survey Nordic balancing markets and imbalance settlement from the Finnish point of view. The aim in this thesis is to find situations, where Finnish resources for balancing have been scarce and to find out if there exists mechanisms that are hindering the price formation in such situations and find proposes to improve price formation. In this thesis the survey is limited to concern only cases, when there is scarcity of up-regulation resources, which means the shortage of resources taking care of situations, when the demand is greater than generation. In the future, the penetration of variable energy resources will presumable also bring up the question of sufficient down-regulation resources, the resources that implement the balancing in cases when there is excess generation compared to demand, but in this thesis these cases are framed out.

The structure of the thesis starts by introducing the background, motivation and the objective in the first chapter. The second Chapter introduces the economic principles of the price formation according to demand and supply. The premise of this thesis is, that the market design choices made in this thesis try to follow the market principles as closely that it is possible.

The third chapter introduces how the Nordic electricity markets are organized. The concentration is on how the electricity market design aims to steer the system towards supply and demand balance, which is a necessary requirement for safe and functioning power system. The framework for Nordic electricity market is explained and different market stages and the principles of energy price formation are presented. The chapter takes also a deeper look to the power balancing markets and introduces an important balancing measure, regulating market, and how its price formation is done. Also an important principle of electricity market in Nordic electricity markets, the imbalance settlement is introduced.

The fourth Chapter discuss about what is meant by scarcity of resources and scarcity pricing in electricity markets. The chapter presents different market imperfections and mechanisms that are seen to hinder the price formation in scarcity situations. Also the approach of Value of Lost Load pricing in scarcity situations and application of Operation Reserve Demand Curve in electricity markets in Texas are reviewed.

In fifth Chapter the aggregated data from Finnish regulating market during time interval 2013-2016 is analyzed in order to find situations when the resources to implement balancing have been short. The hours for which the scarcities have occurred are detected and also the possible causes of the scarcity situations are discussed. As for each hour there is a price for regulating and imbalance price, these price are detected and discussed which kind of signal these prices give to the market participants. In this chapter also the availability of regulating resources is surveyed and the possible variables that have an impact on the resource availability are discussed.

Chapter six discusses the problems in current price formation mechanisms in regulating market and further reflected to the imbalance price. The proposals to improve the pricing mechanism with scarcity adder is presented and its possible impacts to three different stakeholders are analyzed. The seventh Chapter summarizes the conclusions of this thesis.

2. THE ECONOMIC PRINCIPLES OF SCARCITY PRICING

This thesis refers several times to the market principles of demand and supply and compares the practices of electricity markets to this theoretical frame of perfect market model. Because of this it is important first to get familiar with the basic market principles, what is role of scarce resources in economics and how the key mechanism according to the price forming works.

By dictionary, scarcity can be defined as a lack of something which implies further that there is a demand but no sufficient supply to meet this demand. This is also the intuitive and familiar definition and especially used when speaking about natural resources. However in modern economics scarcity refers to every resource or commodity produced from resources with a price, meaning that a price itself is the indicator of scarce resource (Morgan et al. 2009).

Lionel Robbins in his famous Essay on the Nature and Significance of Economic Science defined economics as "the science which studies human behavior as a relationship between ends and scarce means which have alternative uses" and since then the scarcity has been a fundamental concept of modern economics. (Buechner 2014) Economic textbooks explain that as most commodities are not infinite which limits the possibility for supply to meet the demand, the resources are scarce. As there is scarce resources which leads to scarce commodities, these commodities need to have a price. On the other hand, if there is unlimited amount of resource, there is no scarcity and the price of the commodity is zero. So price is an indicator of scarcity, and by the principle of demand and supply under the perfect competitive markets, the scarcer the resource is, the higher the price. (Pekkarinen & Sutela 2002)

Regardless being a fundamental concept and used for defining the science of economics there is no inclusive definition what scarcity really means. Also many different fields in economics has emerged to challenge this fundamental premise of allocation of scarce measures (Buechner 2014).

Prices also have an important role rationing scarce resources, if the price for certain good is zero, presumably large quantities of it would be used. However if the amount of good is not infinite, not everyone can have the amount they want and that could lead in absolute lack of the product. The ration is made through the price system, according to consumers choice of opportunities, those who are valuing the utility of good with exiting price are also willing to pay this price and those who are valuing the utility under this price, choose not to consume it. (Morgan et al. 2009)

Based on the description above, the price has many tasks. The price delivers information between the producers and consumers. The price is a signal which tells how scarce or abundant some resource is. It tells to the producers, how much the consumers value a commodity, and on the other hand, it tells to the consumers, how valuable it is to produce such a commodity.

To understand how higher price indicates scarcer resources and which kind of signals high prices should give both for consumers and suppliers it is useful to take a look in relation between demand and supply by model of equilibrium of competitive markets. The importance of price and how it guides the behavior of consumers and producers can be explained with a simplified model of supply and demand. If we think about one certain commodity, it is expected that when the price of commodity rises, the quantity that consumer want to buy will decrease. This behavior of the demand curve is demonstrated in a figure 1, which presents the relation of the quantity of commodity the consumers want to buy for the certain unit price.

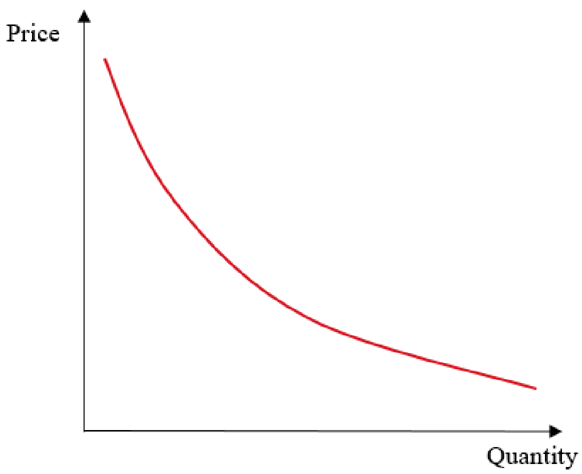

Figure 1. *Demand curve presents the quantity that consumers are willing to purchase with certain unit price.*

The horizontal axis of figure 1 tells the amount of commodity units when the vertical axes tells the price per unit. To keep things simple enough, in the figure only variables are price and the quantity. All the other things which could have effect on quantity of units purchased such as consumers' income, their tastes and prices of related good are assumed to stay constant. (Pekkarinen & Sutela 2002)

The behavior of producers' side can as well be demonstrated with a curve. In figure 2 the behavior of supply side is illustrated.

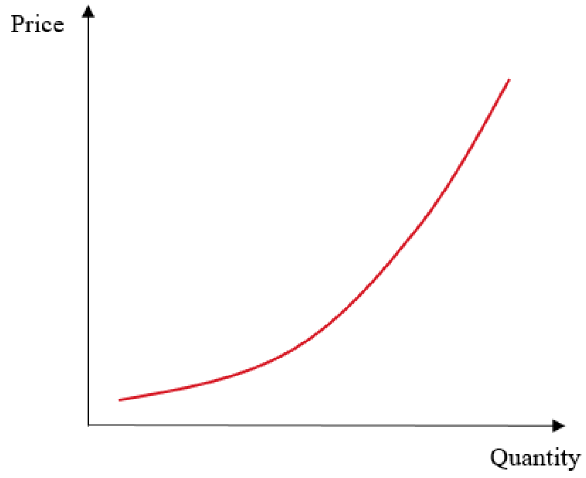

Figure 2. *Supply curve presents the producers are ready to supply with certain unit price.*

The supply curve in figure 2 represents how many units of certain product the producer is willing to sell with certain unit price. The increasing shape of curve can be explained with marginal pricing. We assume the producer aims to maximize profits, which is a remainder of returns and costs. Marginal return is the additional return that producers receive by selling one additional unit of product, so the marginal return is the price per unit of the product. Then again the additionally produced unit increases the costs, and this mark-up of costs is called marginal costs. For producer to be profitable, it is essential, that the price covers the production costs. In order to maximize the profit it is rational for producer to produce amount of units with price similar to the marginal costs. (Pekkarinen & Sutela 2002)

By merging these two curves, the optimal market price and optimal quantity of commodity is found in intersection of the curves. The intersection of these curves will set the equilibrium situation, which is presented in figure 3.

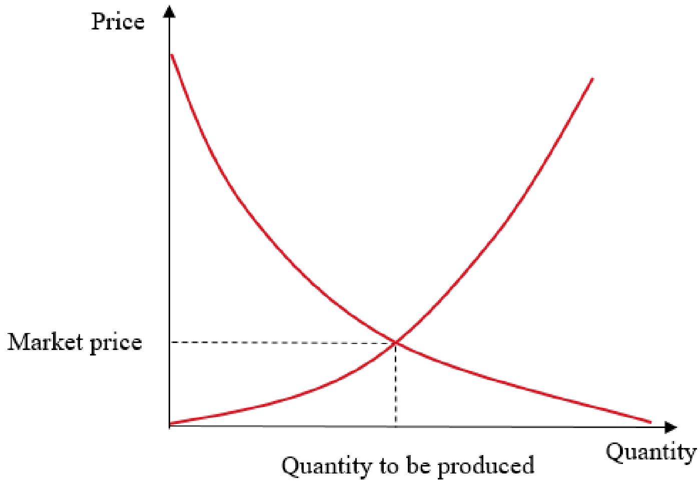

Figure 3. *The market equilibrium is found in the intersection of supply and demand curve.*

In theory, the intersection illustrated in figure 3 between curves will show us the equilibrium between the consumers' willingness to pay and producers' willingness to produce. How and why this equilibrium is achieved can be explained when looking what happens, if the price is not set to the intersection point. If the price would be set to be greater than the intersection point, the producers would be willing to produce more than consumers are willing to buy with this high price, which would lead to the excess of production. If the producers wants to get more of their products to be sold, there is a pressure to push the price down. And again, if the price is set to level too low, the consumers want more products than the producers see profitable to produce, which will eventually leave some people without the product, even they would have been ready to pay the same amount for it as was paid by the one who got it. This kind of situation leads to the shortage of the product. The benefit of the demand and supply mechanism is, that it incentives the producers to produce the commodities that consumers are willing to buy. If there is a shortage of some commodity and consumers' willingness to pay for it, the price should give the producers a signal to make new investments that enables the production of needed units. (Morgan et al. 2009)

Such price forming mechanism is also believed to maximize the overall welfare. This can be explained by maximizing consumer's and producer's welfare, which are presented in figure 4. The figure 4 illustrates a situation, when the equilibrium is achieved and the total price for consumers to pay and producers to receive can be calculated by following:

$$Total\ price = p * q \tag{1}$$

Where p is the market price and q is the quantity purchased with this price.

However, from the consumers' side there was readiness to pay altogether for quantity q the price corresponding to the area limited by demand curve and the value of q in the x-axis. When subtracting the actual total price p times q from the total price consumers would have been ready to pay, the result is consumers' surplus, the profit for the consumers as they get the amount of q with cheaper costs that they were ready to pay. The same idea from the producers' side is, that the producers could have sold q units with a cheaper total price than p times q, more accurately with the price equal the area limited by supply curve and the q in the x-axis. The producers' surplus is the profit that producers get by selling their product with the market price. And as the market price optimizes both, the consumers' and producers' surplus, this means also maximum total welfare. (Pekkarinen & Sutela 2002; Morgan et al. 2009)

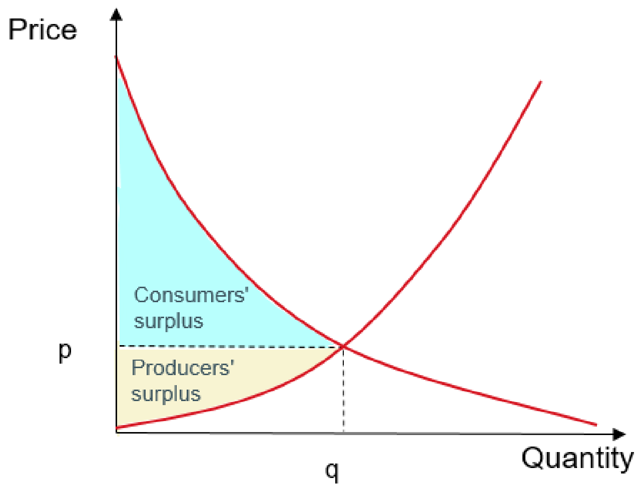

Figure 4. *The equilibrium with price p maximizes consumers' and producers' surplus.*

The theoretical model above bases on the assumption of the perfect competition. The assumption is that nothing else than the demand and supply of all the consumers and producers on the market effects on the price forming. In the perfect competition all the consumers and producers are price takers, which means that that a single producer or consumer, the seller or buyer cannot have alone effect on prices, but they take the price determined via demand and supply curve as given. However, the ideal model does not exist and in the real world, many other things might effect on the formation of price. For example price controls and subsidies for certain producer might lead to situation, when the price stays too low and the price signal to producers is not telling to invest in new production, even it would be needed. Also market power, which means that some market participants may have an ability to alter prices to differ from competitive price.

Another important concept is the price elasticity. Price elasticity can be defined for both, the demand and supply by the relative changes of prices and quantities. For example the demand elasticity can be defined with following

$$Price\ elasticity = \frac{the\ percentual\ change\ in\ wanted\ quantity}{The\ percentual\ change\ in\ price}. \qquad (2)$$

The price elasticity is often negative, which means that the increase in price decreases the demand. In cases when the elasticity is equal or smaller than 1, the demand is inflexible, and again when the value is greater than 1, the price elasticity is defined as flexible. The price is seen more flexible for the commodities for example if there is appropriate substitutes for the commodity, if it is not necessary, if the price change is believed to be temporary and the consumers do have only short time to get used to the price change. (Pekkarinen & Sutela 2002)

3. PRICE FORMATION IN NORDIC ELECTRICITY MARKETS

This chapter concentrates to describe two important processes regarding to power system balancing, regulating market and imbalance settlement. In both processes, the price is in central role and their current price formation is explained here in detail. However, the formation of regulation price and imbalance settlement are not unconnected processes and both are linked to the price formation in day-ahead and intraday markets. To provide a framework of operational environment where regulating markets and imbalance settlement are functioning, the current formation of Nordic electricity markets as well as the price formation of day-ahead and intraday markets are discussed in beginning of this chapter.

3.1 Nordic electricity markets

In the modern society the need for electricity is indisputable. Electricity markets can be thought as a complex whole, which enables to supply society's need for electrical energy. To be able to supply customers, firstly electricity need to be generated and secondly there has to be processes to enable exchanged between producers and customers as well as processes to establish a price for these exchanges. This chapter discusses how these processes are organized in Nordic electricity markets. To be able to supply customers there is also a need for transmission and delivery of electricity for final customers, but these two processes are not under consideration of this thesis and thus not discussed.

The trading of electricity happens in different timeframes and in different market places. A small-scale customer buys energy from retail markets. Retailers procure the volumes they are contracted to sell to their customers either by owning power plants by themselves or buy purchasing volumes from wholesale markets. Electricity contracts between end-consumer and retailer are typically fixed with prices and thus the character of wholesale markets, the volatility of energy prices is not straightly reflected to the prices end customers are paying. There are also available contract types that allows to bind the price to the wholesale spot price, but the fixed price contracts are still in majority position. (Partanen et al. 2015)

In wholesale markets trading happens between large-scale participants. These participants can be either the owners of generation, large-scale electricity consumers or retailers who are procuring the electricity they are contracted to sell for their end-customers. The market participants can trade physical electricity either in power exchange or between market participants as bilateral trade. (Partanen et al. 2015)

The Nordic market area consist of seven countries, Denmark, Estonia, Finland, Norway, Lithuania, Latvia and Sweden, and a power exchange where market participants from these countries can trade is currently Nord Pool. Nord Pool is a wholesale marketplace, where it acts as a counterparty for all trades. In Nord Pool the trading period is one hour and market participants can trade electricity in day-ahead markets regarding the hours of following day. Besides the day-ahead market, Nord Pool provides also an intraday market, where trading can take place continuously before the actual delivery hour. (Partanen et al. 2015)

Besides the Nord Pool, where trades always lead to actual delivery of electrical energy there are also financial markets, where market participants can hedge themselves against the risks they face because of price variations in day-ahead markets. In financial markets the commodities are different financial forwards. The market place for Nordic market participants for these financial products is Nasdaq OMX Commodities. (Partanen et al. 2015)

3.2 Price formation in day-ahead and intraday markets

The trading in day-ahead market is based on the planning of market participant. Energy buyers, the retailers or the ones who use the energy for their own needs as for example big industrial customers forecasts the anticipated energy volumes needed to meet the demand during the hours of following days and also decide how much they are willing to pay for the desired volumes. The energy sellers holding the generation plants also plan how much they are prepared to produce the energy and at which price. (Nord Pool 2017a)

The exchange in day-ahead market is organized as a closed auction where the system price is set based on demand and supply. According to the planning market participants submit their bids including the information of the offered or procured volumes and price marginal within participants are prepared either to sell or buy the volume in question. Bidding deadline for hours of following day is at 12.00 central European time. From the information of demand and supply included in bid an algorithm calculates a system price for each hour of following day. After calculation and announcement of system price the trades are settled. These contracts of sold and produced energy do lead to physical delivery of energy. A figure 5 presents an example how demand and supply curve formed from day-ahead bids settle the system price. (Nord Pool 2017a)

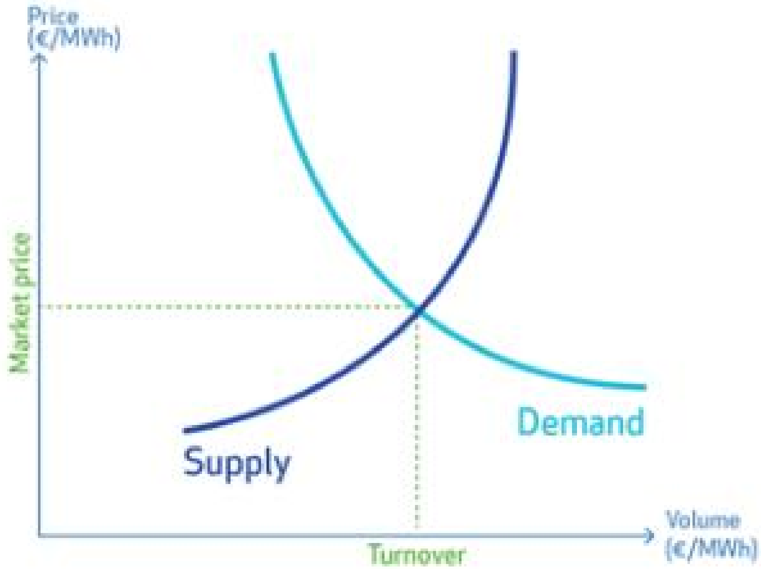

Figure 5. *Formation of day-ahead system price (Nord Pool 2017a).*

For electricity markets to be suitable choice for society it has to provide economically effective solution. As it can be detected from the figure 5, the intersection between the supply and demand curves do set the market price and according to the economic principles explained in Chapter 2 market price clears the market by finding an equilibrium between buyers' willingness to pay and sellers' profit.

In competitive markets the market prices are driven down to the efficient cost levels which normally reflects the true marginal costs of producing the energy. This price is achieved when the incremental cost of producing one kWh of energy is the cost of the most expensive power plant needed to balance the system in day-ahead timeframe. The Nordic electricity mix is diverse which mean also diversity in marginal costs of a running plant. Some plants are capital intensive but may have really low running costs, this kind of plants are hydro, wind and solar. Due to low marginal costs and high capital costs, it is profitable for these plants to run year around. Then again there is technologies with lower capital costs but considerable running costs, which are not profitable to run with lower price than their marginal cost. These technologies do run less frequently, on those moments, when the offered volumes of cheaper energy are not enough to meet customers need. (Nord Pool 2017b)

Under competition, if the producer will offer energy with a higher price than marginal cost of running the plant, there is a risk that producers bid is too high and his product will not be sold. Offering energy with lower price than marginal costs means simply losses for producer, these market principals give the incentive for producers to offer their electricity with the price close to their marginal prices.

In practice the pricing in day-ahead market is also affected by limitations of transmission capacities. The Nordic market area is divided in bidding areas where the different prices may occur due to the congestions on connectors. In the case, where there would not be any limitations of transmission capacity, the system price would be the price overall the Nordic market area. However in cases when there is not enough capacity to transfer the energy between areas to satisfy the market results, congestion occurs and the transmission system operators (TSO), the units that are responsible of electricity transmission in Nordic countries, either need to do countertrades or divide the Nordic market area in price areas with differing prices. (Partanen et al. 2015) The Nordic trading area divided in different price areas is presented in figure 6.

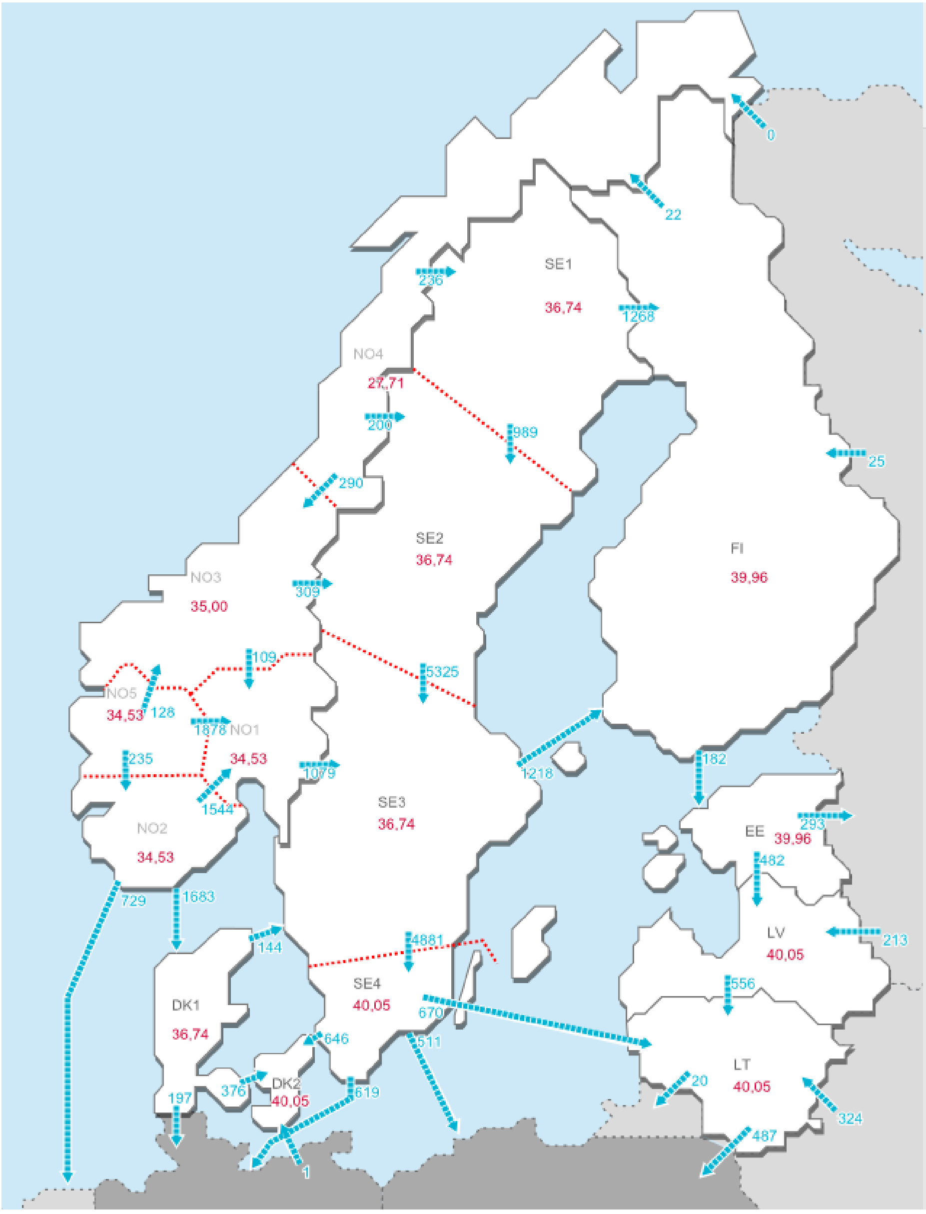

Figure 6. *Price areas and flows in Nordic market area 12.5.2017 9.00 EET. (Stattnett 2017)*

Figure 6 presents the day-ahead results of 12.5.2017 for hour 9.00 in Eastern European time. The blue arrows represents the power flow between price areas and the red dashed line is representing the boundaries between the usual price area divisions. For example the same price between areas SE2 and SE3 shows, that there is no congestion between these two areas. The example of congestion can be detected for instance between price areas FI and SE1, where the prices are different.

From the balancing point of view, day-ahead market can be understood as a balancing tool, which aims to set in equilibrium the forecasted demand and forecasted production. However, the day-ahead results are settled 12 – 36 hours before the actual delivery hours, and the forecasted situations may change after volumes in day-ahead market are settled. The weather variable production forecast might have be changed due to more accurate weather forecasts or there might be changes also in forecasts of consumption. Also there is possibility that some generation plant has tripped from the network, and the market participant has to purchase somehow energy it was committed to produce and sell.

The intraday markets provide a supplement to the day-ahead market. It gives market participants a chance to balance their own supply and demand with the deficit or surplus they are facing after day-ahead market is closed. Intraday market is a continuous market where market participants can trade around a clock until gate-closure-time which is one hour before delivery. Unlike in day-ahead market, the price is formed with first-come first served principle and the price is not same for all traders. (Nord Pool 2017c)

Intraday-markets have an increasing role in current situation in electricity markets as the penetrating intermittent generation requires short-term adjustment. In markets that function well, the prices in intraday should reflect the value of flexibility and especially, when there is a scarcity of flexible sources, the intra-day price should rise. (ACER/CEER 2016)

3.3 Balancing in Nordic electricity markets

One of the core operations of transmission system operator is to keep the electricity system in balance, more accurately to ensure that production and consumption of electricity are in equilibrium at each moment and that the system frequency stays in desired margins of value 50 Hz. The balancing can be understood as a process with different time frames, which starts already in day-ahead and intraday-markets when the market participants balance their own production and consumption by buying and selling energy. However achieving the absolute balance is not possible as this trading is done before actual delivery hour and so there is often differences between forecasted and actual situation. Because of these differences there is still need for fine-tuning the balance in real-time and this is a responsibility of nominated transmission system operator.

Different regulations and agreements direct the way that balancing is enforced and balancing services are procured. In the national legislation level, Finnish law of electricity markets states that Finnish transmission system operator is responsible for ensuring the balance in the electricity system of continental area of Finland. The law states, that terms and conditions for procuring the balancing services must be equal and non-discrimination for all participants of electricity markets. Terms and conditions should also not include any unjustifiable terms that would limit competition, however the requirements of system security and efficiency need to be taken into account and these terms and conditions should also provide appropriate incentives for market participants in order to support the balancing measures. (Electricity market act 2013)

The more detailed level of how TSO can implement the balancing is presented in European Union legislation level. European Union has released a set of electricity codes and guidelines which contains rules according to the cross-border electricity network operation. The final version of network code on electricity balancing, Balancing Guideline was published in March 2017 and it establishes both operational and market rules that govern the balancing markets in Member States. The Balancing Guideline for example states that the balancing energy pricing should create positive incentives for market participants in keeping and/or helping to restore the system balance and pricing should also enable an economically efficient use of demand response and other balancing resources. (European Commission 2017b)

Another important document regarding balancing is a System Operation Agreement (SOA), an agreement on the operation of the interconnected Nordic power system between TSO's of Denmark, Finland, Norway and Sweden. The Nordic interconnected power system is further divided in two different synchronous systems, The Nordic synchronous system includes the subsystems of Finland, Norway, Sweden and Eastern-Denmark. The Western Denmark belongs to Central-European synchronous system. The agreement states that each TSO is responsible of the operation of its own subsystem. (ENTSO-E 2006)

However as the Nordic subsystems are interconnected, there are benefits rising from collaboration between TSO's. In SOA the TSO of each subsystem agrees how this collaboration between TSOs in power system operation, including balancing, is realized. The objective is to benefit from advantages entailed by operation of interconnected subsystems and operate it jointly in a way that the existing resources and power trading is utilized in most efficient manner. Regarding the balancing, the co-operation between TSO's should lead in minimizing the balancing costs when the balancing resources of subsystems belonging to the same synchronous system are utilized. (ENTSO-E 2006)

When talking about balancing it is good to make a notion about the terms used in this thesis. There are two terms, balancing market and regulation market that can be in colloquial language often used to mean the same thing. The Balancing Guidelines defines balancing market as an "entirety of institutional, commercial and operational arrangements that establish market-based management of balancing" (European Commission 2017).

This definition includes a variety of different measures applied in Europe to operate balance and fulfill the responsibility of system operator. Also in Finland and in another Nordic countries there is different measures for this. One of these measures is regulation market. Regulation market again by definition of SOA is a market place for regulation power, where market participants can give bids of their resources that can implement the balance regulation (ENTSO-E 2006). This thesis follows this choice of definitions, meaning that balancing and balancing markets are a general level notion including all measures to achieve balance between demand and supply, when regulation and regulating market are included in balancing market, meaning one certain product to enable balancing. However this is only a choice made here, and in many publications these definitions may be used differently. The regulation market will be discussed in more details in Chapter 3.4.1.

3.4 Balancing products

In Nordic countries there are different products for balancing. Besides the technical differences, products can be grouped in purpose of use, the manual and automatic activation and as well if they are paid for capacity or energy. The description of balancing products in this Chapter is from Finland's perspective, but in many cases the description applies also in other Nordic countries that are forming the synchronous system. However, there are also some non-harmonized differences between countries (ENTSO-E 2016a).

The balancing in respect to the frequency response is implemented by using the Frequency Containment Reserves for normal and disturbance situations. The Frequency Containment Reserves for normal operation (FCR-N) keep the frequency within marginal of 0,1 Hz. Frequency Containment Reserves for disturbance (FCR-D) again are activated automatically in situations when frequency drops or rises over this 0,1 Hz marginal compared to the reference value of 50 Hz. For both FCR-N and FCR-D the activation time is fast as they respond automatically to frequency drops and rises in time frame of seconds to couple minutes. (ENTSO-E 2016a)

Fingrid procures FCR-N and FCR-D reserves from national yearly and hourly markets as well as from other Nordic countries and from Russia and Estonia. These products are not taking part to the energy-only markets and the costs of these reserves are covered by tariff fees of balance and grid services and the participants offering the reserve will get the payment for reserving the capacity even they were not used. (Fingrid 2017a, Fingrid 2017b)

Besides the frequency containment reserves there is frequency restoration reserves which are operating reserves that restore the frequency back to target value of 50 Hz and these reserves also restore back the activated FCR reserves. The Frequency Restoration Reserves are again divided in automatic product (aFRR) and in manual product (mFRR). The automatic aFRR is a relatively new product and it was introduced to reserve markets 2013 (ENTSO-E 2016a). Automatic FRR product is procured from hourly markets and it is also paid the compensation for available capacity (Fingrid 2017c). However, in this thesis the main interest is in the manual frequency restoration reserve product that is procured from the market place, where the main remuneration is received through the activated energy, not by reserving capacity. The manual frequency restoration reserve is managed through regulating markets and is described in detail in next chapter.

3.4.1 Regulating market

The mFRR is currently the main resource in Nordic power system to balance the supply and demand and also for handling the situations with congestion management in normal and disturbance situations. Activation of mFRR replaces FCR and aFRR and balances the frequency to its target value (ENTSO-E 2016a). The mFRR can be divided in different sources, the voluntary bids that are getting remuneration only for energy they are serving and the contracted that gets remuneration also for the capacity.

The main source of mFRR is the regulating capacity provided by market participants that still after day-ahead and intraday results do hold resources that can implement 10 MW power change or 5 MW power change in case of electronic activation within 15 minutes (Fingrid Oyj 2017d). In each subsystem of synchronous area TSO of subsystem maintains a regulating power market, where market participants can submit the bids of their available resources. In Finland the TSO maintaining the regulating market is Fingrid. Currently the bids need to be submitted to the TSO 45 minutes before the actual delivery hour and after that the bids become binding (Fingrid Oyj 2017d). The figure 7 presents the different types of regulating bids.

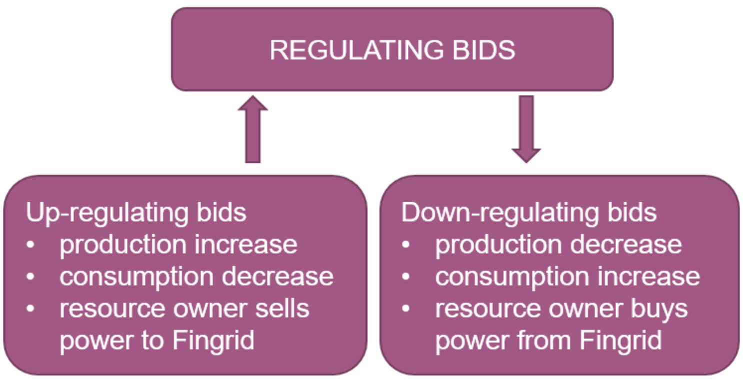

Figure 7. *Types of regulating bids. Adapted from (Fingrid Oyj 2017d).*

As presented in figure 7 the regulating can be either up-regulating or down-regulating and bids can regard either generation or consumption. Up-regulating is needed when the demand in system is greater than supply and down-regulating is again needed in situations when there is excess generation compared to demand. The review of down-regulation situations is framed out in this thesis, so further use of word regulation refers to up-regulation.

The bids submitted to TSO includes information of the offered resource such as the capacity that market participant is committed to hold for delivery hour and the bid price in unit €/MWh. The market participant will get the remuneration only for energy that is activated for balancing needs, so the market participant is not receiving any payment for reserving the capacity for regulating needs. Market participants taking part to regulating power market are not obligated to bid, so their participation is completely voluntary, and for this reason later on these bids are referred as voluntary bids.

The use of regulating energy brings costs to TSO as it is the buyer of the energy. The costs of regulating energy for TSO are mainly covered by the electricity traded within the imbalance settlement (Fingrid Oyj 2017b). The imbalance settlement process is described in detail in Chapter 3.5.

Besides the voluntary bids from market participants there are also resources that are not remunerated only for the energy they are producing but also for capacity reserved. This pre-contracted capacity is reserved in order to ensure that TSO has always sufficient amount of capacity to respond in dimensioning fault, which means that the power system need to always withstand the loss of an individual component. This principle is further referred as N-1 criteria (ENTSO-E 2016b). Each TSO can procure the capacity to suffice N-1 criteria the way they see as a best and also voluntary bids can be used to suffice N-1 criteria.

In Finland the pre-contracted reserve consists currently of gas-turbines that are either owned or leased by Fingrid and of capacity procured from the balancing capacity market. Currently the capacity of the gas-turbines is around 1230 MW (Fingrid 2017b). Balancing capacity market was established in spring 2016 in order to procure capacity from market participants beforehand to ensure that TSO has sufficient amount of capacity to respond in dimensioning fault also in situations where the gas-turbines are having maintenance breaks (Fingrid Oyj 2017e). Until the end of year 2015 Fingrid had also contracted disconnectable loads, however these contracts expired in the end of 2015 (Fingrid Oyj 2014). The costs of these fast disturbance reserves are covered mainly by Fingrid’s grid service tariff, so these cost are shared for all grid users (Fingrid Oyj 2017b).

3.4.2 Price formation of regulating price

Regulating price means the realized price that is paid for activated regulations. The price is determined for each hour and each regulation area (ENTSO-E 2016b).The price is paid per MWh, which means that market participant bidding voluntarily will get the payment only if their bid was activated and only for the amount of energy activated.

In the situation when there is no congestions between subsystems, all bids from different subsystems within synchronous area are merged as one Nordic merit order list. From this list the bids are activated in price order for regulating needs (ENTSO-E 2016a). Like this the regulation resources from the whole synchronous area can be used in lowest price possible. When a congestion between the subsystems occurs, the subsystem is separated as its own regulating area and the bids from that area are separated from Nordic merit order list as its own list (ENTSO-E 2016a).

At the moment both, the voluntary bids as well as the pre-contracted reserves are taken into account when forming the Nordic merit order list. This makes the list a mixture of capacity payment and energy-only principles. The main principle when activating the bids is that the bids are used in price order. However, when some of capacity is receiving also capacity payments, all resources in the list are not in equal position what it comes to the competition in market and how the capacities are remunerated. The market participants giving voluntary bids will get the revenue only if their bid is activated, those resources that are pre-contracted get their revenues for their reserved capacity even if they are not activated. However all the market participants holding appropriate resources have possibility to participate in that market that they see most profitable.

Between countries in synchronous area there are differences how these two resources with different procurement philosophy are handled in Nordic merit order list. In Finland and Sweden the voluntary bids are activated before the pre-contracted bids as the pre-contracted capacity can be understood as a subsidized. In Denmark and Norway these bids are however not distinguished. (ENTSO-E 2016a) Giving some capacity payment receiving resource different position in merit order list than to the other brings incoherence to the rules and also can disturb the price signals and competition.

During the operational hour, the last activated bid from the merit order list will determine the price of energy for the whole hour that TSO’s are paying for the energy activated for regulating needs. The pricing of regulating is based on marginal pricing which means that all participants whose bids were activated are paid the same amount for MWh.

However the situation described above holds only when there is no congestions between borders and no physical restrictions in operation of power system. In a case of congestion on the power line linking the two price areas the bids from merit order list cannot be anymore used in price order. For example if the capacity of power lines linking Sweden and Finland are fully used in a direction that the electricity is imported from Sweden to Finland, in case of Finland being deficit area, the balancing bids from other areas cannot be used without violating the physical capacity limitations of the power line. In such a cases, the areas are diverged as their own balancing area. In a case, when Finland is diverged as its own balancing area, the bids from Finnish market participants submitted to Fingrid diverge from the Nordic merit order list to its own list and the bids are used in price order for Finnish purposes. (ENTSO-E 2016a)

There are also cases, when TSO needs regulating for some other reason than balancing the production and demand. These cases are called special regulation and for example when TSO needs to manage congestions or there is some other specific cases, TSO can use the bids available and pass the price order. The price paid for the market participant providing regulation in these cases are paid with pay-as-bid principle and the special regulation price is agreed to be always higher or equal with the possible up-regulation price. So if during the same hour there is need to activate both, bids for special regulation and also for the usual balancing purposes, the bids with higher prices will be used for special regulation and those prices will not affect the regulating price. (ENTSO-E 2016a)

However, also special regulation situations may cause a big need of resources and especially a loss of an interconnection can lead to situation where power system's resources are scarce. With the current rules how the pricing of these special regulations is organized the up-regulating price will stay lower than which really would be the price of last used regulating resources. So even there would be a scarcity with regulating resources, it is not shown in up-regulating marginal price and especially not in imbalance price, which significance is explained in next chapter.

3.5 Imbalance settlement

The imbalance settlement is a fundamental principle in European electricity markets. The market participants or more accurately the balance responsible parties that can present one or several market participants are obligated to plan themselves in to the balance for each hour. However during the operational hour there might be imbalances that are taken care by TSO's balancing products. After the operational hour all the deliveries of energy between different units are measured and compared to the planned deliveries and withdrawals and the differences between planned and measured volumes are treated as imbalance power, which is financially settled between the TSO and balance responsible parties.

The Balance Responsible Parties are companies that manages a balance obligation. Balance responsible party can manage the obligation on behalf of itself or it can represent other participants. They have made an Imbalance Settlement Agreement with eSett, the company that manages the operational functioning of imbalance settlement in Finland, Norway and Sweden. Balance responsible parties also need to have an agreement with TSO, that TSO will be an open supplier for balance responsible party. (eSett 2017)

Each market participant's generation and consumption has to be addressed to balance responsible parties, which again aggregate the supply and consumption and reports it to the TSO. During real-time delivery, the Balance Service Unit which in Nordic is TSO balances the balance responsible parties need to balance their supply and demand and again the balance responsible party does balance the market participants, which belongs to their balancing obligation. The process described is called the chain of open suppliers and it is demonstrated in figure 8.

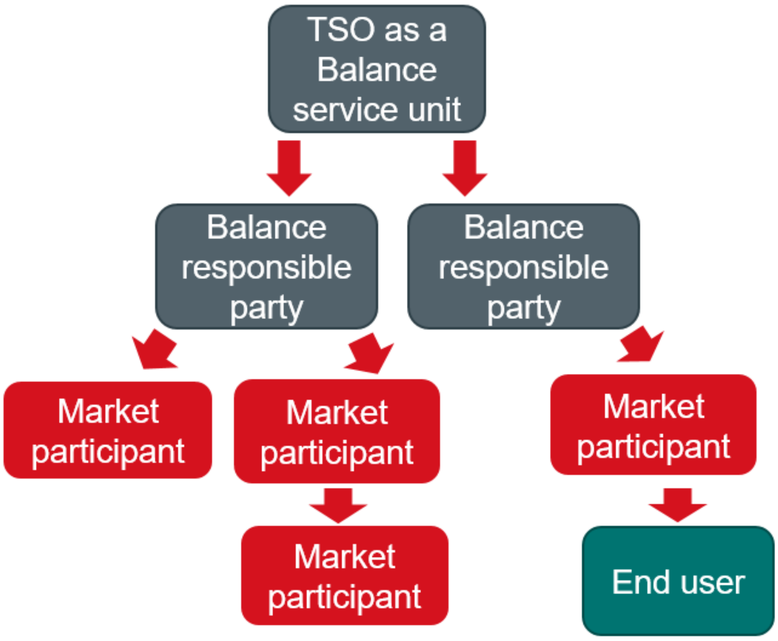

***Figure 8** Imbalance settlement open supplier chain. Adapted from (Fingrid Oyj 2017f)*

In the figure the arrows presents the hierarchy of chain of open suppliers and imbalance settlement. In this thesis the concentration is only in the highest level of chain and so regards only the imbalances that are settled between the TSO and balance responsible party. After the operational hour all the deliveries between participants are measured and the imbalances are charged.

The design of imbalance settlement has an impact on balancing responsible party's behavior. If there would be no financial consequences of imbalances, there would not be incentives for market participants to stick to the balance obligation. The balancing agreement forbids balance responsible parties from systematically use imbalance power as a procurement of electricity (Fingrid Oyj 2017). Regardless the forbid, it is also important that the financial incentives should be also designed in way that causing imbalances is not attractive. The next chapter explains how the imbalances are currently priced and which kind of incentives the current pricing system in Nordic does create.

3.6 Price formation of imbalance price

The balance of system is one of the important goals for designing regulating market and imbalance settlement, so there should be appropriate financial incentives provided to balance responsible parties to steer towards this goal. The first top level incentive for balance responsible parties is the requirement, that they are all financially responsible for their imbalances. The pricing of imbalances currently support the target of staying in balance, which means that causing imbalance should not be seen as a profitable option. Nordic balancing philosophy states that pricing of imbalances should reflect the value of activated energy needed to balance imbalances of balance responsible parties. However currently only the price originating from regulating market is taken into account when calculating the imbalance price and the automatic reserves FCR and aFRR are not considered when calculating the imbalance price (ENTSO-E 2016a).

The calculation and settlement of imbalance volumes in Nordic countries is based currently on two separate imbalances, production and consumption. The figure 9 presents how the power to be settled is calculated in these imbalance models.

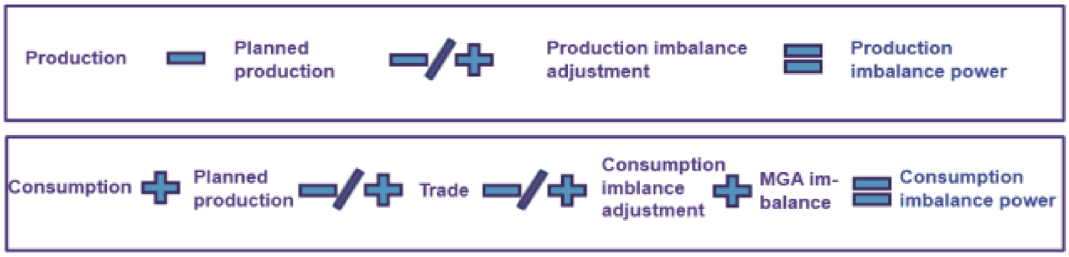

Figure 9 *Calculation of production and consumption imbalance powers.(eSett 2017)*

As it is presented in figure 9, the volume of production imbalance is calculated as a difference between the metered actual production and the planned production taking into account the adjustment that is made in case if the balance responsible party has provided regulating energy for the markets. In the case when the actual production is greater than planned, the balance responsible party’s imbalance is surplus, and in the case when actual production is less than planned, the imbalance is deficit.

The consumption imbalance again is calculated as a difference between consumed and purchased energies. In figure 9 the consumption and the trades where the balance responsible party has been the seller presents the consumed energy, and again the planned production and the trades where the BRP has been the buyer of energy are considered as energy that balance responsible party has purchased. Also in consumption imbalance calculation there is adjustment in case that balance responsible party has provide TSO with regulating energy. The Metered Grid Area (MGA) imbalance in figure 9 stands for the sum of injections and withdrawals of certain grid area, which should be zero in case if all the reported values from the metered grid area are correct (eSett 2017).

These two imbalances are priced differently, two-price model is applied for production imbalance and one-price model for consumption imbalance. In both price models, the prices are depend on the direction of regulation for the hour. In two-price model the price is different for the balance responsible party's imbalance depending if the party’s imbalance is deficit or surplus as for the one-price model the price is the same for both. (eSett 2017)

For production imbalance, during an up-regulation hour, the balance responsible party is responsible for buying the energy from eSett to settle their deficit with up-regulating price and sells its energy with day-ahead price (eSett 2017). This means that there is a strong incentive not to be deficit as the up-regulating price is typically greater than day-ahead price and the energy would have been cheaper to trade in day-ahead market and being surplus at least does not give any profit as the energy could have been sold with the same price in day-ahead markets.

If the hour is a down-regulation hour, the balance responsible party settles its deficit by buying the energy from eSett with day-ahead price and sells its surplus with down-regulation price. Now there is a strong incentive not to have surplus, as there would have been a better price for energy in day-ahead market. And again being deficit does not bring any profit as the energy could have been bought with the same price in day-ahead market. And finally, if during the hour there was no balancing energy activated, the imbalance price for both, deficit and surplus imbalances is the day-ahead price.

For consumption imbalance a one-price model is applied. In this model both the deficit and surpluses are settled with same price depending on the direction of regulation. When direction is up, the price for both, deficit and surplus is up-regulating price and again down direction lead on down-regulating price. With no activated balancing energy, the price is a day-ahead price. The pricing of imbalances is presented in figure 10.

	Up-regulation hours	Down-regulation hours	Hours with no direction
Two-price model for production imbalances			
Negative production imbalance of BRP	Up-regulation price	PX market price	PX market price
Positive production imbalance of BRP	PX market price	Down-regulation price	PX market price
One-price model for consumption imbalances			
Negative consumption imbalance of BRP	Up-regulation price	Down-regulation price	PX market price
Positive consumption imbalance of BRP	Up-regulation price	Down-regulation price	PX market price

Figure 10 *Pricing models for imbalances. Two-price model is apllied for production imbalance and one-price model for consumption imbalance. The PX market price in figure stands for market price set in day-ahead market. (eSett 2017)*

At the moment neither the regulating price nor the imbalance price is visible for market participants in real time. The regulating price which implies also the imbalance price is published in Nord Pool no later than 60 minutes after the operational hour (ENTSO-E 2016a). This means that the market participant will face the price only afterwards.

As a result of the imbalance pricing model and the fact that the price is not visible in the real time, the balance responsible parties do face the risk to purchase their imbalance volumes with higher price that they would have purchased it from day-ahead market or intra-day market. These costs in case of hour being defined as up-regulating hour and balance responsible party having a deficit imbalance are pure costs without any benefit and rationally these costs are wanted to be avoided. In case the balance responsible party being surplus during up-regulating hour, the production imbalance does not get any profit compared to situation that the production would have been sold in day-ahead market. Instead being surplus in consumption imbalance during up-regulating hour usually brings profit to the balance responsible party.

The day-ahead market price is currently a reference price where market participants can compare their final prices they face in imbalance settlement as they could have purchased or sold the energy with day-ahead market if they could have forecasted their consumption and production right. There should also be a strong link between the intraday price and the imbalance price, as the trading in intraday can be done much nearer the actual delivery time and it gives chance for those participants that need still to fix their balance between production and consumption. So the participants that need to still purchase energy have a market place where it is at least at theory possibility to buy the electricity with cheaper price.

Intraday-market is expected to become more important with the larger share of variable generation penetrating to the power system (Scharff & Amelin 2016). Intraday trading gives a possibility to adjust the changes in production and consumption forecasts that are known after the closing of day-ahead markets but at least one hour before the actual delivery hour. The price link between intraday and imbalance price should be designed such that the trading in intraday should seem more attractive to market participants than face the results of imbalance settlement.

4. SCARCITY PRICING

This chapter takes look to what is meant by scarcity in electricity markets and how it should be priced. The price is an important variable when designing electricity market, and here its importance and effects are discussed a well as which might be the consequences when the price signals from electricity markets are not appropriate. Here also the concept of Value of Lost Load and its connection to electricity demand curve is introduced and thesis also takes a look how scarcity is priced in Electricity markets of Texas.

4.1 Scarcity in electricity markets

Scarcity in electricity markets refers to situation, when the tight supply occurs at the same time with a high demand and the resources to balance the system are scarce. Electricity is not comparable with many other commodities as there is not yet efficient measures to store it and utilizing electricity requires special transmission system where supply needs to meet the demand at each moment, which makes electricity a commodity that cannot be decoupled in time. Thus the scarcity in electricity markets is not a long term condition and the occurrence of scarcity situations is always dependent on instantaneous consumption and production. (Wilson 2000) This means that scarcity can occur in the same power system, which might be facing even surpluses of resources depending on moment.

To ensure system requirement of balanced demand and supply for each moment, the energy system needs flexibility. Flexibility in the system means that system can adapt to rapid changes in demand or consumption (ACER/CEER 2016). The resources providing flexibility for the system are controllable parts of consumption or demand that can enforce a rapid change of power and support the system to achieve the balance. In the future, with developing technology also energy storages might provide flexibility for the system balancing (Stattnett, Fingrid, Energinet dk, Svenska Kraftnät 2016).

Scarcity in flexible resources can increase threat of involuntary interruption of electricity supply. The duration and impact of these interruptions as well as frequency quality are indicators for security of supply, which again is one of the priorities of European energy policy. In Directive 2005/89/ of European Parliament and Council, the security of electricity supply is defined as “an ability of an electricity system to supply final customers with electricity” (European Parliament and Council 2006). The security of supply can be understood as an entirety divided in three different sections that all contribute to energy system’s ability to supply the final customer. These three different sections are security of fuel resources, security of system operations and generation adequacy. (IEA 2016) Generation adequacy is defined as the capability of generation capacity to meet the load in the power system, however this term and its definition itself includes an assumption, that only the generation has ability to change to achieve the demand. As this traditional approach is nowadays at least in some level challenged with demand response, we will use later on instead of term generation adequacy a term resource adequacy, which will include also the demand responsibility as a resource to achieve the balance between supply and demand.

In Nordic area the flexibility sources has relied strongly on hydropower plants with reservoir. In Finland and Denmark the residual need for balancing is recovered by thermal plants and with connections abroad and in there has yet not been significant issues with resource adequacy. (Stattnett, Fingrid, Energinet dk, Svenska Kraftnät 2016).

European Network of Transmission System Operators' (ENTSO-E) makes the adequacy assessment for Pan-European region. The newest assessment, Mid-Term Adequacy Forecast based on probabilistic methodology gives the outlook for years 2020 and 2025 of resource adequacy and according its findings, none of the countries in Nordic region suffers from lack of generation adequacy, when taking into account the operating reserves. However, the report states that adequacy problems are expected to rise in 2025 and the same concern is shared also by Nordic TSOs as the electricity generation mix is changing due to the drivers of climate targets and these raises concerns about resource adequacy (Statnett et al. 2016). It is also important to notice, that ENTSO-E's adequacy analyze results do assume that there is possibility to import electricity from neighboring countries in scarcity situation. When there is unavailability of connections adequacy problems may rise. (ENTSO-E 2016c)

Due to European Union commitment to reach its climate targets, the large share of renewables need to be integrated into the energy system. For year 2020 EU's Renewable energy directive has set the target of 20 % of energy consumption to be generated from renewable sources and the energy and climate goals for year 2030 has set the target to be 27 %. In electricity generation this has led into growing shares of weather depend renewable generation. During years 2015 and 2016 the amount of new installed wind power capacity in Finland was about 949 MW and cumulative installed capacity in the end of year 2016 was 1539 MW. Same numbers for Sweden and Denmark were respectively 1108 MW and 454 MW for new installed capacity during years 2015 and 2016 and the cumulative installed capacity in the end of year 2016 resulting 6519 MW and 5227 MW (Wind Europe 2017).

This large and yet growing integration of variable renewable energy has led to two effects which both have an enervating effect on the security of supply in terms of generation adequacy. The output of variable renewable energy as wind and solar is highly depend on weather conditions and the capacity of these plants is not available during moments of poor weather conditions for generation. This means that the system cannot rely on that the built renewable capacity would be available if the moment of peak-load occurs at the same time with poor wind and solar conditions. System might experience stress not only during peak demand moments but also during moments when weather conditions are not appropriate for wind and solar generation and there is relatively high demand. To ensure there is each moment an adequate amount of resources to meet the demand, system needs flexibility that will help to balance the demand during moments, when generation from renewable sources is not sufficient enough. In short, integrating large share of variable renewables increases the need to invest in assets that are providing the flexibility for power system. (IEA 2016)

The simultaneous trend is that the large integration of renewables do reduce the hours that conventional plants run. Usually the marginal cost of variable renewable energy is also cheap compared to mid-merit and peak-load capacity and for example subsidies for renewable energy has pressed the price to low level. Also the price development in wholesale power prices has been has been downwards. In energy-only markets this means that in the long run the investments in new generating capacity which could provide flexibility for the system gets more risky and might lead in some conventional generators exiting the markets. So in short, the need for flexible assets is growing at the same time when there is no incentives to invest in new generation that would provide flexibility for the system. (IEA 2016)

4.2 Role of prices ensuring the resource adequacy

Maintaining the real-time balance on the grid to ensure the frequency quality and continuous supply of electricity efficiently requires market design. In market design energy prices play an important role as a design variable. The fundamental question in market design from security of supply perspective is, if markets are able to offer the needed resources to enable supply and demand to meet at each moment. (Wilson 2000; IEA 2016) Prices are the main incentives for market participants and they have an effect on market behavior. This requires design of such prices that does not create inappropriate incentives but instead provide effectivity and efficiency supporting incentives (Nobel 2016).

If the markets would be ideal, during the scarcity the energy price would rise to the limit when there is no more customer willingness to pay according to the economic principles introduced in Chapter 2. The current energy-only markets however include market imperfections and at the present situation the prices in the markets do not provide signals that would incentive for flexibility.

The most popular market imperfection and also the most common explanation for lack of scarcity prices is the existence of price caps that are set in too low level. Price caps are usually considered as the main explanation for preventing the prices to rise during scarcity-ty events (Joskow 2008). As explained above the future scenery is that other than variable renewable plants are needed but might only run during some hours per year. In energy-only market this means that this run for few hours has to cover both, marginal and fixed costs. To be able to recover these both, the price during these running hours should be allowed to rise to high level, considerably above to their marginal costs.

When the current electricity markets were designed the high prices would have been considered as abuse of market power and not acceptable by politicians and there is one reason for introducing the price caps to the market. Reasons for price caps also include technical reasons and as well as limiting abuse of a dominant position and shield consumers from high energy prices. (European Commission 2016)

In the new situation, when other than variable renewable generation is highly dependent on prices during scarcity hours these caps have created dis-incentives for new investments. From the demand side, high prices provides an incentive to consume less, so price caps preventing prices to rise are not providing the right incentive. (IEA 2016)

In majority of European Union Member State the price cap for day-ahead market is set to the value of 3000 EUR/MWh. This cap is however implemented rather as a technical constraint than with the intention to limit prices. In the current situation these price caps and their level need new consideration and in the new proposal for internal market regulation requires that if price caps need to be implemented, they should not be set under the value of lost load, which will be explained in detail in next chapter (European Commission 2016).

Even the price caps have been the common and most popular explanation for lack of scarcity prices, recently there has been also doubts if the price caps are the only mechanism to hinder the price formation during scarcity hours. A strong argument for other reasons behind lack of scarcity prices is that the prices during scarcity situations have not hit the current price ceiling. Possible actions that system operators use in order to maintain the reliability, like having out-of-market bilateral agreements with certain resources that can be used for balancing, has an important effect on suppressing the prices during scarcity. (Joskow 2008)

4.3 Value of Lost Load pricing

Besides the capped prices there exist also other market imperfections. When reflecting the economic theory with rising prices in scarcity situations to the existing electricity markets, the severe incoherence is that most of the final customers excluding the big industrial electricity are not exposed to real-time prices of electricity which leads to the lack of demand curve in real-time markets.

In this chapter as well as in next Chapter 3.4 this thesis refers often to the literature and concepts of U.S market structure and it is good to make a remark that the market structure of U.S differs in many ways from the structure of Nordic electricity markets. In U.S market designs are based on real-time price, a single price that varies within the time, which period is taken closer to real-time and this price does include also costs of balancing, which in Nordic electricity markets are handled separately (Nobel 2016) . In Nordic context the closest interpretations for real-time price are regulating price and imbalance price, however it is important to understand that there is a fundamental difference in word real-time price between U.S and Nordic context. In Nordic, the regulating market provides the resources to respond to real-time balancing needs and the ex-post imbalance settlement prices derived straight from regulating prices do reflect this real-time value of electricity. The regulating and imbalance energies have their own prices and are charged only for the volumes respective to regulating and imbalances. It is also noteworthy, that in Nordics the price is set for one hour, when in many U.S electricity markets the real-time price is set for each 5 minutes.

Stoft (2002) has named market imperfections which lead to lack of demand elasticity as first demand side flaw. The first demand-side flaw is the lack of real-time metering and billing of end-consumers the second flaw being the lack of real-time control of power flow to specific customers. Even the real-time metering has developed and in Finland many consumer can follow their electricity use in hour level the real-time prices are not reflected to the real-time electricity consuming. Due to these market flaws the demand side is not responding to real-time price which further means that the supply and demand side may not intersect and the system operator is the one who need to decide how the price is achieved (Stoft 2002).

In the Nordic regulating markets, the price is determined to be the price of the last activated regulating bid. This means that the price is determined only based on the supply curve and the amount of demand like demonstrated in Figure 11. The demand seen in figure in 11 has no price elasticity and does not tell anything how much the demand side values the supply, so the real demand curve with the information of the consumer's valuation is missing.

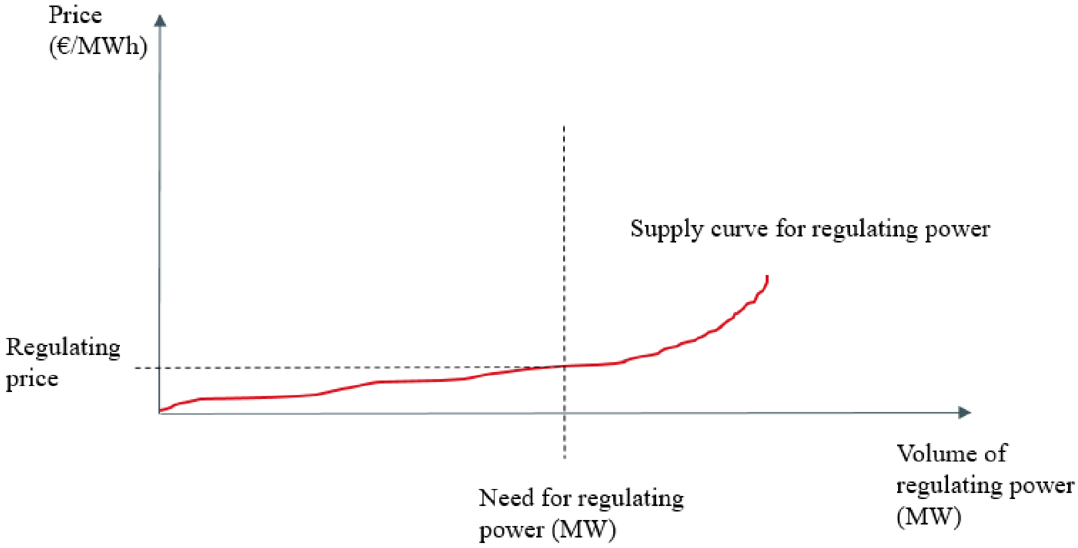

Figure 11. *The price setting for regulating energy in Nordics.*

For Finnish regulating market, in the cases, where the activated voluntary bids are not enough to suffice the demand, the price stays the same as the last activated regulating bid. Before the load shedding takes place, Fingrid can use pre-contracted capacity or other out-of-market measures to ensure the balance in the power system. As these pre-contracted bids have remuneration also for capacity, it is unlikely that the bid from these sources would be greater than the highest voluntary bid, which means that the price stays at the last activated voluntary bid and does not develop even more capacity would be activated. The extreme example is the case, when TSO need to shed load involuntary, and with the current price formation, the price can still stay the same as the last activated regulating bid, which might be stayed much lower than the consumers would have valued the continued supply of electricity.

For society the load shedding load is expensive way to ration demand and there is no possibility to make distinction between who need or value the electricity more than others. Another approach of forming the real-time price is the Value of Lost Load –pricing (VoLL-pricing), which is based on the demand side valuation of not being cut off. The VoLL pricing is regulatory action, in which the real-time price is set at the value of lost load when the load has to be shed. (Stoft 2002)

Value of lost load (VoLL) is a measure often referred to evaluate the value that consumers are willing to pay for continuous energy supply without interruptions. VoLL is usually presented as a unit Currency/MWh and it helps to review resource adequacy rules and to build a scarcity pricing rules. (IEA 2016)

In order to easy interpretation of VoLL it can be referred to mean a certain value of a price cap. However it is important to understand, that even it can be used as a price cap, it is not that in its usual meaning. No offers after that should be accepted, not because there is need to protect consumers for the higher price, but because VoLL is a boundary value, there should not be customer willingness to pay after price exceeding VoLL. (Hogan 2005)

Even the need for estimate like VoLL is well justified, the actual calculation for its value is not a simple task. When thinking about the electricity consumer side it is easy to understand that VoLL cannot be same for everyone, for example household consumer can think of very different price for involuntary interrupt compared to big industrial electricity consumer, which operation is depending on electricity supply. So VoLL is for sure depending on the customer or sector type. Other things that VoLL is depending on are timing and duration of the outage and the timing of notification of outage. As variables effecting the value of VoLL are diverse, also different estimates for value of VoLL do vary. (IEA 2016)

Different evaluations for values of loss load has been made in different studies. The values do variate between 3000 and 28 000 €/MWh (Pöyry 2016). For example the London Economics have estimated the best appropriate single number for Value of Lost Load to be 16,940 £/MWh (London economic). In this thesis the valuation and calculation of VoLL is not discussed, but it is assumed to be level of 15 000 €/MWh, noteworthy greater than the current price cap for regulating power 5000 €/MWh.

Finnish Energy authority also defines parameters to calculate the costs of interruption in electricity network, which can also be compared to Value of Lost Load. The reasons behind the costs are different, as the interruption originating from internal network fault is different than the situation, when there is not enough production of electricity for everyone. However the effect on consumers is the same. Finnish authority of Energy has used the values of 11 €/kWh to estimate the valuation of harm caused by interruption. The value is calculated for monetary value of year 2010 and that value originates from the researches (Silvasti et. al 2005, Honkapuro et. al 2007).

4.3.1 Operating Reserve Demand Curve

The Operating Reserve Demand Curve (ORDC) was introduced by Hogan (Hogan 2005), who stated that the reserve demand curve would improve the determination of prices in scarcity conditions. In U.S the operating reserves are generation that is available on short notice. These reserves are available to respond to imbalances caused by unpredictable changes in demand or loss of a generation unit or transmission line (Hogan 2013). Operating reserves provide regulation to balance load fluctuations and so they can be interpreted to provide same kind of service as regulation capacity in Nordic markets.

The reserve demand curve should raise the price towards the average VoLL when the amount of available reserve decreases, so this curve works as an scarcity adder. The lack of demand effect in pricing results flawed prices in the scarcity situations, the operating reserve demand curve would add the demand effect to the pricing in scarcity situations. Setting the price always at the running costs of the most expensive generator, as the competitive market model suggests, is relevant when there is an excess capacity, but when capacity becomes scarce, there should be a demand curve that sets the price. (Hogan 2005)

The functioning of the Operating Reserve demand curve is based on the Value of Lost Load and the probability for such a contingency that system operator need to shed the load involuntary. In case when the involuntary load shedding takes place, any increment of reserves would reduce the load curtailment, so the price for the last reserves that could prevent the load shedding should be set to the value of VoLL. At other levels of operating reserves, the increment would value the VoLL multiplied the probability that the net load would increase in the coming time interval such, that the remaining reserves would reduce to the level when load shedding takes place. This probability can be presented with the Loss of Load Probability (LOLP) curve. The description above is illustrated in figure 12.

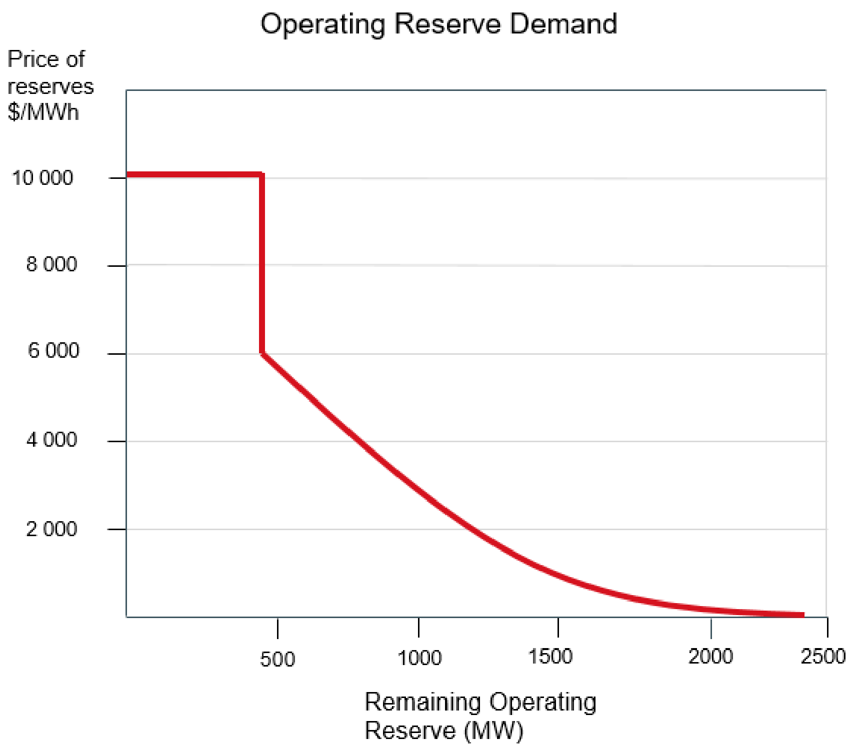

Figure 12 *Illustration of Operating Reserve Demand Curve. Adapted from (Hogan 2013).*

In the figure the y-axis represents the price and in x-axis there is the availability of operating reserves. In this illustrative example figure from (Hogan 2013) the VoLL is set at $10 000/MWh and the minimum level of reserve requirement is assumed to be 500 MW i.e when there is only 500 MW of operating reserves left, the involuntary load shedding takes place. Above the 500 MW the shape of the curve is determined with the LOLP function. The discontinuity at the reserve level with 500 MW in figure is due to reducing load, which reduces the probability for load curtailment. (Hogan 2013)

In mid-year 2014 The Electric Reliability Council of Texas (ERCOT) enforced the Operating Reserves Demand Curve to correct the energy prices to reflect the true value of flexible resources. In ERCOT area the VoLL is currently set to the value $9000/MWh and the minimum contingency level is set at 2000 MW. Figure 13 presents statistics of the use of scarcity adder during year 2015.

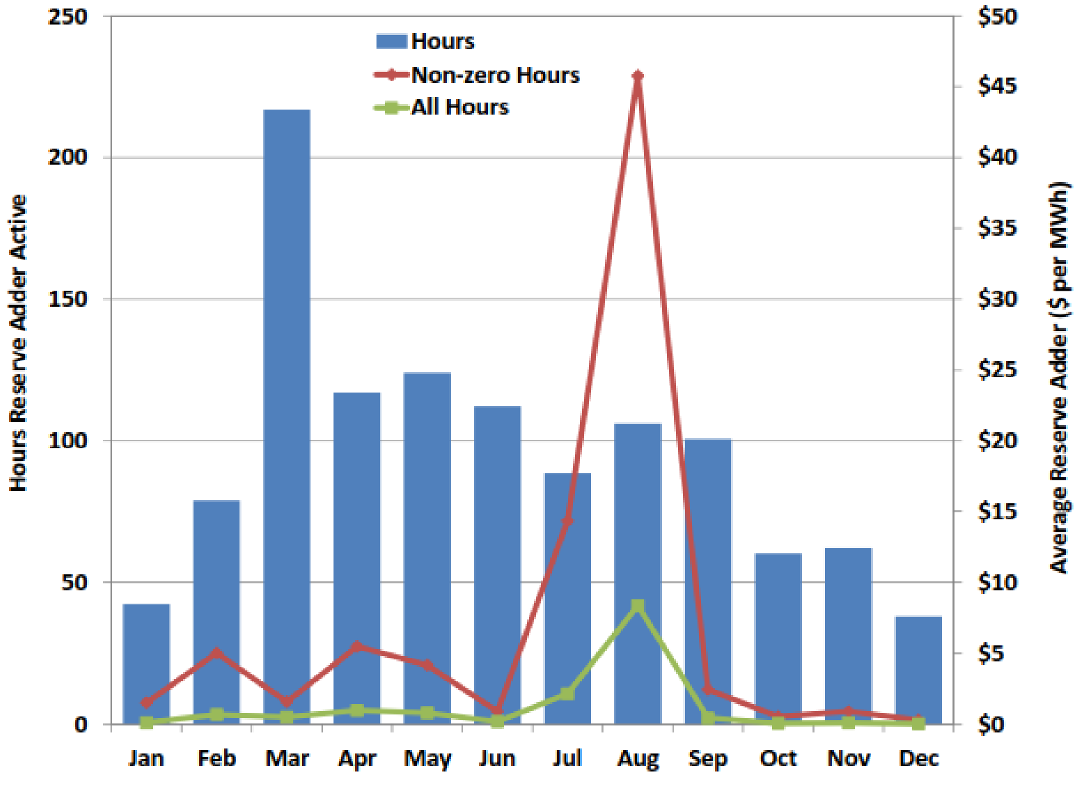

Figure 13 *The effect of the Operating Reserve scarcity adder in year 2015. (Potomac Economics 2016)*

In the figure 13 the blue bars presents how many hours per month the operating reserve adder has been affecting prices. The green curve presents the average price effect per month for all hours when the red curve does present the average price effect when only the hours when price adder has been used. According to this figure, the price effect has not been steep. However the Market report of ERCOT states, the results do not indicate that implementation of operating reserve demand curve is ineffective. The largest effects occur when conditions are such that poor supply and high load conditions fall on simultaneously. (Potomac Economics 2016)

The idea of using LOLP function and VoLL is also applied in Great Britain. In November 2015 Ofgem, the national regulation authority of Great Britain presented the Electricity

Balancing Significant Code Review, which resulted in large reforms regarding the imbalance arrangements. One highlighted problem regarding the imbalance price formation was the use of pre-contracted reserve products that had fixed activation prices without reflection to real-time conditions of the power system. The use of this pre-contracted fixed-price capacity did damp the imbalance price, which again prevented the creation of right incentives to balance responsible parties. (ACER/CEER 2016)

To be able to create appropriate incentives for electricity markets in Great Britain, the Reserve Scarcity Pricing function was implemented. This function uses also LOLP and VoLL, and the price determined by the function replaces the reserve price if it is greater than the original activation price. Like this the price can be determined by the merit order list of balancing bids but in cases where the price is not sufficient to reflect scarcity, the reserve scarcity pricing function will increase the price. This scarcity adder is applied only to the imbalance price, not in the balancing price. (ACER/CEER 2016)

5. SCARCITY SITUATIONS IN FINLAND

In order to take a look, which kind of price signals the current regulating market in Finland gives to market participants in scarcity situations, we need to take a deeper look in actual situations when the regulating bids have been scarce. This chapter analyses the availability of regulating bids provided by market participants and the situations when these bids are nearly used up.

5.1 Data used for retrieving the scarcity situations

The data used for this thesis is retrieved from the database that manages the commercial information regarding the power system that Fingrid operates. The data from years 2013, 2014, 2015 and 2016 includes all the regulation power bids submitted to Fingrid including the information for which hour the bid is assigned, the amount and direction of offered capacity as well as if the bid was activated and if activated, for which purpose. Also in the case of activated bid, the information of the marginal price of trade is included. The raw data was handled in MS Access database tool, which enabled to search and group the relevant data. The original data includes also the pre-contracted bids from Fingrid's own or leased gas turbines, and between the winter period 1.12.-28.2. the bid from peak load consumption reserve as well as from spring 2016 the bids with origin of regulating capacity markets.

From the raw data the aim was to find certain hours, when the voluntary based resources in the Finnish merit order list have been short. From the market perspective approach was to find out to what level the voluntary bids are used per hour. First SQL data search was done such that all the bids excluding the Fingrid's own bids and the peak load reserve bids were aggregated per hour. Like this the list of hours and the sum of voluntary bids for each hour was retrieved. Then all the activated voluntary bids excluding the Fingrid's own and peak load reserve bids were also aggregated per hour. These two list including the sum of bids and sum of activated bids per hour were united per hour and compared such that all the cases, where the sum of activated bids divided with the sum of available bids exceeded 50 % were collected. For year 2016 due the way that original data was formed there was no possibility to exclude bids which originated from regulation capacity market, so the amount of capacity procured from regulation capacity market was checked from Fingrid's web page where the amounts of pre-contracted capacity from the capacity balancing markets are published (Fingrid Oyj 2017f). This amount published in web page was reduced manually from the relevant hours to get more accurate result for the year 2016.

The major part of the data used in this thesis is also able to get straight or be reproduced from data which is available public. Fingrid publishes per hour a sum of regulating bids submitted by Finnish market participants and again Nord Pool publishes list of all regulating bids, including also Fingrid's own bids. Fingrid publishes also the activated regulating energy as well as a separate activated energy for special regulations. However in scarcity situation it is about the ability of capacity to meet the demand, not about the energy. So the data used here includes the amount of activated bids in power, not in energy. An example will help to understand this difference: Assume that for hour a total sum of voluntary bids is 500 MW. The situation develops such, that during the hour all bids are activated, but only during the last half of the hour. This means that the energy activated for balancing is 250 MWh, but 500 MW of power was activated. Even 250 MWh of energy remain unused, there was no more up-regulating resource left at the actual moment it was needed. In many cases, the energy activated for sure gives a good estimate, but in cases when the bids are not activated for the whole hour, there is no much point to compare available bids with activated energy. Instead, the comparison is made between the available capacity and the activated capacity. The lack of information on how much capacity was activated makes it difficult for market participants to do later analysis, as the scarcity of resources might not be revealed by comparing activated energy and available bids.

5.2 Availability of voluntary based regulating bids during 2013-2016

Figure 14 presents the duration curves of sum of voluntary based regulating bids for years 2013 – 2016. From the data presented in figure 14, the pre-contracted capacity of Fingrid's gas turbines was excluded, so the actual available capacity has been at least N-1 MW greater. The pre-contracted bids are excluded as this capacity is assumed to be dimensioned in respect with N-1 principle, so the capacity of pre-contracted gas turbines bid for balancing purposes is always at least the dimensioning fault and there is no significant variables affecting to the volume.

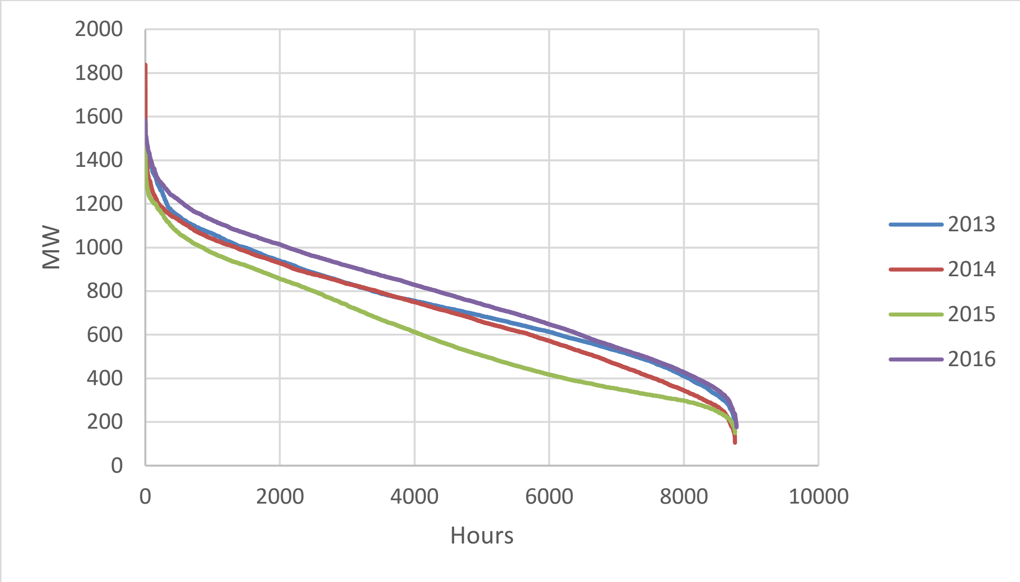

Figure 14 *Duration curves of available voluntary based regulating bids.*

The figure shows that the availability of voluntary based bids varies a lot within a year and there can also be detected differences between the years. The table 1 shows a more detailed information of available bids for each year.

Table 1 *The key numbers for availability of voluntary regulating bids.*

Year	Average	Median	Minimum	Maximum
2013	745,4	729	155	1722
2014	714,5	716	105	1838
2015	615,7	568	149	1563
2016	794,8	794	176	1583

Table 1 represents the average, median, minimum and maximum of voluntary based bids for each hour. As it can be detected from the figure 14 and table 1, year 2015 shows clearly decreased sum of balancing power bids. The decrease compared to two earlier years could be explained by mothballing large amount of conventional generation units in Finland. According to the Finnish Energy authority's report of security of supply, during year 2015 more than 900 MW capacity did exit the markets, which presumable has also an effect on capacity available for up-direction balancing (Energiavirasto 2015).

This however does not explain the clear increase, when we get to the year 2016. It is presumable that the decommissioned power during year 2015 was also not available during year 2016. New installed capacity during year 2016 was mostly wind power which is not considered to provide up-regulating bids to the market, as for wind power with low operational costs and subsidies it is profitable to try to sell everything in day-ahead market. So it is not presumable that during year 2016 there would have been more generating capacity for regulation in Finland available than before. One explanation can be that in the end of year 2015 Fingrid's contract with disconnectable loads were ended and it is presumable that at least part of these disconnectable loads can provide regulating capacity for regulating markets. The value for year 2014 for this disconnectable load was 385 MW and it is likely that the value for 2013 and 2015 were also similar. However all these assumptions are not verified with the data available.

As seen from figure 14 the sum of voluntary based bids per hour varies a lot. Besides observing of differences in volumes between different years it is also interesting to see how the availability of regulating volume varies in different time scales. Figure 15 takes a year 2015 as an example, how the seasonal differences do effect on the availability of regulating bids.

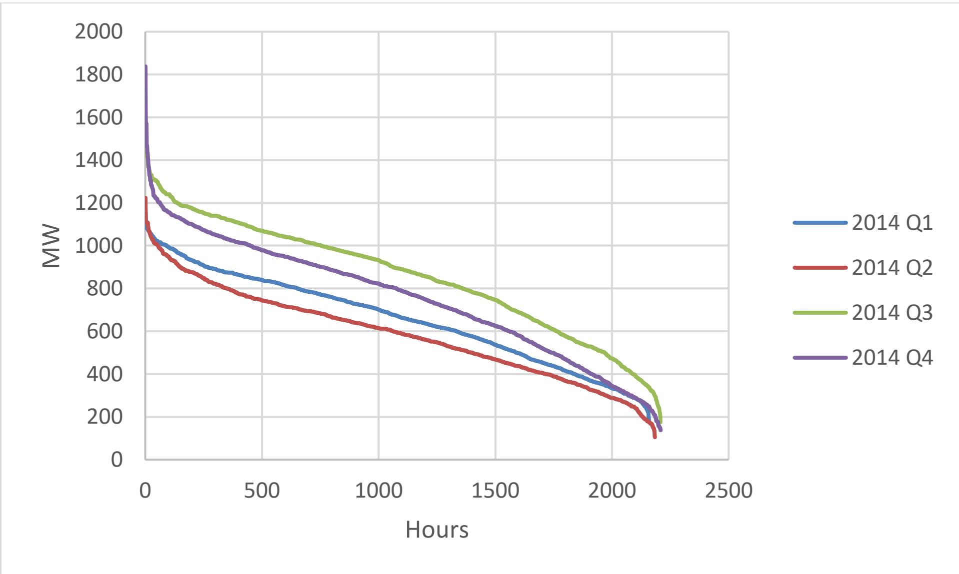

Figure 15 *Duration curves for quarters of year 2014.*

Figure shows, that periods Q1 and Q2, which means the time period from January to June, have the lowest level of available voluntary based regulation capacity. One reason for seasonal variation is the role of hydro power as a regulation provider. The weather conditions do affect the water reservoirs and typically the floods and periods of heavy frosts.

It is also presumable, that some share of the bids are depending on the situation between being sold already in day-ahead market or to bid to the regulating market. This could be seen for example when comparing the price in day-ahead market and sum of balancing power bids per hour. Higher day-ahead market usually means that more generators were needed already in day-ahead time scale and so these same generators do not bid on regulation markets. The correlation between the day-ahead price and sum of up-regulating bids hour is detected in figure 16.

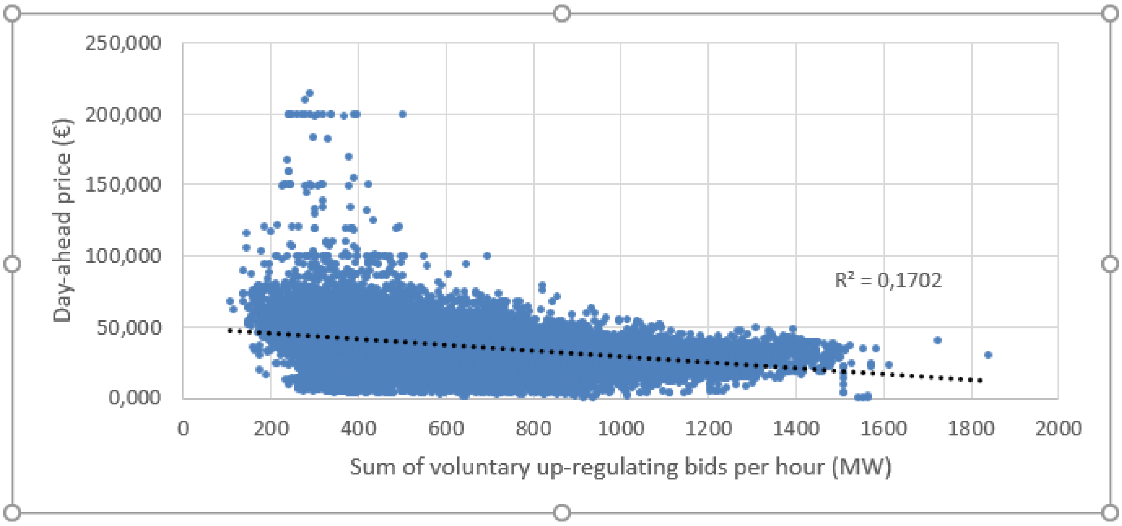

Figure 16 *Correlation between day-ahead price and availability of voluntary up-regulating bids.*

The data chart in figure 16 includes all the hours from years 2013 – 2016. The trend is decreasing, which indicates that with hours with higher day-ahead price the availability of up-regulating bids is lower. The correlation coefficient is 0,17 which proposes that 17 % of variation can be suggested to be depended on day-ahead price, which further implicates that some of those generators that have an option to bid also in regulating markets did sell their generation already in day-ahead markets. It is also noteworthy, that figure 16 shows that when there has been price spikes in day-ahead markets, the availability of regulating bids has been low.

Also the variation within the hours of day is presumable, as the day-ahead price varies within the day according the expected need of energy. The figure 17 demonstrates how the curve shape of day-ahead price is almost a reverse with a sum of up-regulating bids.

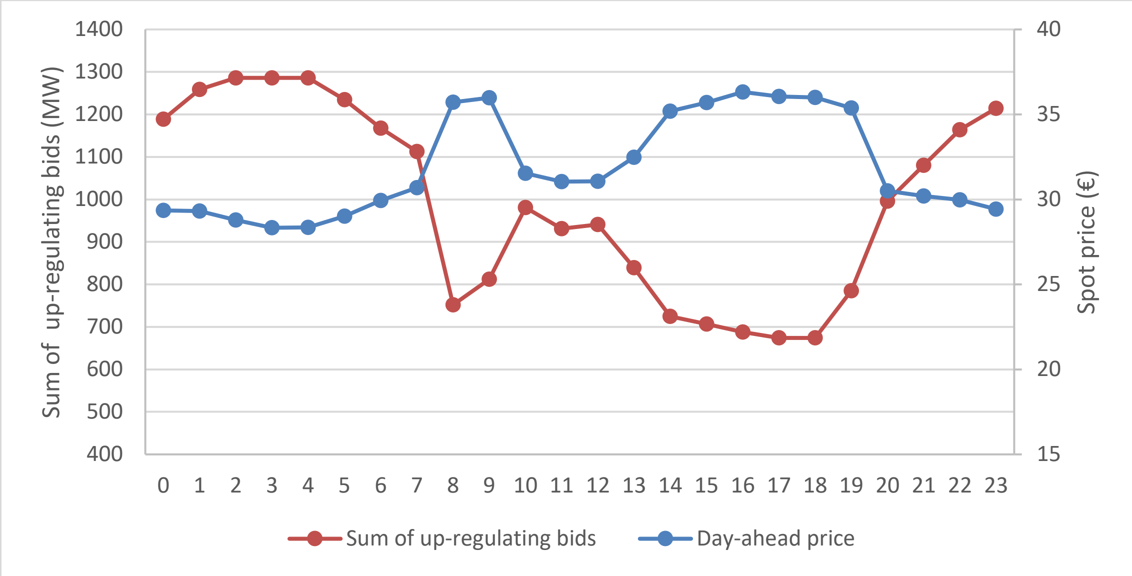

Figure 17 *Regulating bids and day-ahead price 29-12-2016.*

Figure 17 supports the assumption, that there is a connection between the day-ahead price and availability of up-regulating bids. This also shows that the variation inside the day can be significant, as in the figure the 8 the difference between maximum and minimum is 612 MW.

5.3 Scarcity occurrences 2013-2016

There is no a specific rule to define the scarcity situation. Here the approach has been to choose those hours, when the use of voluntary based bids has been considerable. The amount of activation of voluntary based capacity is compared to the amount of available voluntary based capacity, and those hours where the result of comparison has been greater than 50 % are counted. This approach is chosen due to the fact, that after the voluntary based bids are exploited, the energy-only market based resource is scarce.

From the perspective of power system the power shortage situation occurs when the sub-system cannot hold the amount of reserves respect to N-1 rule. (Fingrid Oyj 2017g) And as the fast disturbance reserve owned or long-term contracted by Fingrid is dimensioned according to the N-1 rule also from the power system point of view the system is near to the power shortage situation defined in Fingrid's management of power shortage precept when the voluntary based bids are used till the end. However it is good to notice, that here is made an assumption to simplify the defining of scarcity situation. In reality TSO might have per hour more than amount of N-1 the fast disturbance reserve. The actual available capacity depends of the maintenance breaks of the gas turbines, so depending on the moment there might be pre-contracted reserves available more than N-1 rule requires.

In table 2 there is listed the number of hours per year, when the certain share of voluntary based balancing bids were used. As the table below includes only the observation of voluntary bids, there might have been also situations, when voluntary based bids have been jumped over because of technical reasons or there has been special regulations, and the fast disturbance reserve has been activated and some voluntary based bids might have not be used.

Table 2 *The use of voluntary bids.*

	Year 2013	Year 2014	Year 2015	Year 2016
50 % of voluntary up-regulating bids were used (h)	59	148	110	35
60 % of voluntary up-regulating bids were used (h)	27	85	48	15
70 % of voluntary up-regulating bids were used (h)	10	51	26	9
80 % of voluntary up-regulating bids were used (h)	8	19	18	3
90 % of voluntary up-regulating bids were used (h)	3	5	7	3

The table 2 shows, that especially during the years 2014 and 2015 there have been clearly more situations, when more than 50 % of voluntary bids were activated. This is also in line with the figure 13, which shows that during years 2014 and 2015 the availability of bids were lowest. From the table it can also be seen that the year 2016 has been different as there has been remarkably less cases where voluntary based bids were exploited more than 50 %. This is in the line with figure 13 there has been more voluntary regulating bids.

As the table above includes only the observation of voluntary based bids, there might have been also situations, when voluntary based bids are skipped over because of technical reasons or there has been special regulations, and the pre-contracted reserves have been activated and some voluntary based bids might have be not used. Also these situations can cause scarcity situation, but these cases are framed out from this thesis

To take a deeper look in scarcity cases the scarcest cases where 90 % or more of the voluntary based bids were used are chosen to be analyzed. All these cases are represented in the table below.

***Table 3** 18 scarcity hours from years 2013 – 2016 with their features.*

No.	Time (EET)	Sum of bids (MW)	Sum of activated bids (MW)	Activated bids for special regulation	Finland as own regulating area?	FI Spot price (€/MWh)	FI regulating price in defined direction of hour (€/MWh)
1.	9.9.2013 9:00	852	802	0	Yes	72,14	up 500
2.	9.9.2013 10:00	516	490	0	Yes	62,05	up 2000
3.	18.10.2013 18:00	1033	1018	1018	No	51,00	down 49,40
4.	17.3.2014 5:00	714	659	524	Yes	26,95	up 42
5.	17.3.2014 6:00	572	572	570	Yes	37,60	up 48
6.	21.3.2014 4:00	1026	991	1141	Yes	18,83	spot 18,83
7.	21.3.2014 6:00	718	678	827,4	Yes	30	spot 30
8.	21.3.2014 7:00	500	470	655,4	Yes	35,47	spot 35,47
9.	10.2.2015 8:00	393	383	0	Yes	42,06	up 1000
10.	10.2.2015 9:00	447	407	0	Yes	41,14	up 500
11.	29.9.2015 6:00	241	241	0	Yes	36,77	up 2000
12.	7.10.2015 9:00	182	172	0	Yes	76,28	up 500
13.	6.11.2015 16:00	311	311	0	Yes	39,1	up 500
14.	6.11.2015 17:00	303	303	0	Yes	55,08	up 500
15.	23.11.2015 8:00	347	337	0	No	89,76	up 1999
16.	22.1.2016 6:00	570	560	0	Yes	42,75	up 3000
17.	22.1.2016 7:00	420	385	0	Yes	85,08	up 1000
18.	26.1.2016 6:00	881	881	654	Yes	31,94	up 299

One conclusion from table 3 is that almost in all cases Finland was diverged to its own regulating area. This means that there has been a congestions between Finland and other subsystems in synchronous area. In these situations the Finland has been depend the Finnish regulating list as there has been no possibility to utilize regulating bids from other subsystems.

5.3.1 The cause of scarcities

Here the scarcity situation depends on the amount of bids available and the total amount of the possible imbalance. The availability of bids was analyzed in chapter 4.2 and the imbalances originate from differences between forecasted and actual consumption and production. The scarcities occur when the availability of regulation bids is not enough to cover the imbalance.

In seven cases out of 18 there was need for special regulation and in these cases the special regulation did occupy majority of voluntary based bids available. For cases 4, 5, 6, 7, 8 and 18 there was an Urgent Market Message (UMM) regarding the unplanned unavailability of interconnectors (NP UMM 2017). Even there was no UMM available regarding case 3, it is supposedly that these regulations, as implemented as a special regulation, were also due to the interconnector. It is also worth of noticing that the all the selected scarcity situations in table 3 during year 2014 were due to special regulation.

For 6 cases out of 18 there was an UMM regarding the unplanned unavailability of production in Finland (cases 1,2,9,10,12, 16). Unplanned unavailability means that the production plant has tripped from the network and cause an imbalance. During these cases there was no special regulation and all the cases were handled as normal balancing between demand and supply.

In six of the selected scarcity cases the sum of available bids was over the year's average (cases 1,3,6,7,16 and 17). In remaining cases the sum of available bids were under the average. Especially during the year 2015 all the selected scarcity hours have a low availability of voluntary based bids. Especially the cases 13 and 14 shows that the scarcity situation can occur also in a situation, when the need for regulating is moderate, but the availability is poor.

5.3.2 Price signals of scarcity situations

With the current pricing rules, the regulating price affects straight to the imbalance price which again is the price that should reflect the realities of the power system. If there has been a scarce situation with regulating resources, the imbalance price should reflect that.

The average balancing prices for each year are reported in table 4.

Table 4 *The average up-regulating price, imbalance purchase price and imbalance selling price.*

Year	Average up-regulating price	Average imbalance purchase price	Average imbalance selling price
2013	45,35	37,15	45,30
2014	39,74	32,31	39,71
2015	35,60	24,64	35,52
2016	36,87	28,33	36,81

When comparing the average prices with the prices in table 3, it can be detected that in six cases with special regulation the price has stayed in the same level with the average price, when again cases with no special regulation involved the prices are rising significantly higher than the average. This observation is in line with the rules how the price is formed in special regulation cases. However, the prices in special regulation cases do not give the market participant a signal, that there power system regulating resources have been scarce.

6. SCARCITY PRICING AND ITS IMPACT ASSESSMENT

The present regulating and imbalance price formation mechanism does not give the appropriate price signal that takes into account the consumers valuation of energy in situations when the regulating resources are scarce. Thus it may not incentive the market participants to support the system when it is needed. In this chapter the problems of present practices in price signal formation of regulating and imbalance price are defined. This chapter also proposes alternative measures to improve the design of regulating markets and imbalance settlement and the possible impacts of these proposes are assessed.

6.1 Defining the flaws of present regulating market and imbalance settlement

In the power system, where variable generation has a large share of total generation, the present regulating and imbalance price formation mechanism may not give the appropriate price signal in situations when the regulating resources are scarce. In situations when the power system is facing a power shortage, all available resources that can either increase generation or decrease consumption should be exploited. This kind of situation should send a price signal that either triggers the demand respond or shows that there is need for further investments in regulating markets.

There are four fundamental reasons that can prevent the formation of price signals that reflects the scarce value better. First problem occurs, if the market participant cannot see the prices in the relevant time-frame. Secondly the present trading and imbalance settlement period is too long to reflect the real time regulating needs of power system. The third problem is the management of special regulation which is presently handled with pay-as-bid principle and is not affecting the imbalance price. And lastly present pricing mechanism in Nordic regulating market and further in imbalance settlement lacks demand curve and takes not into account the Value of the Lost Load.

A first problem is invisibility of the prices. At the moment the regulating price per price area is published in Nord Pool's website 60 minutes after the actual delivery hour. If the support for power system from market participants in scarcity situations is wanted action, there has to be visible real time price for which the market participants can respond to. This is a necessary requirement for all further suggestions and development, as it does not matter how right the price signal in scarcity situation is, if it is not visible. The importance of price publication is also noted in Balancing Guideline, which states in Article 12 that TSO should publish information of offered volumes and offered prices as soon as possible, but no later than 30 minutes after the relevant market time unit has ended. However balancing guideline also notes that information has to be published at a time and in a format so there is no competitive advantage or disadvantages (European Commission 2017b).

In the end of November 2016 Fingrid started a pilot of publishing the up-regulating price in real-time when there is only 100 MW of voluntary bids left for regulating, which should remove the problem of invisible price development in scarcity situations. However after the release of the pilot there has not been situations when there would have been less than 100 MW voluntary bids left. (Fingrid Oyj 2017h)

The second problem is, that the current timeframe for calculating the price of scarcity situation is too long. Currently the regulating market trading period as well as imbalance settlement period is one hour. However causes of scarcities are unpredictable and the need for regulation is not always constant over the period of hour. The figure 18 demonstrates this well.

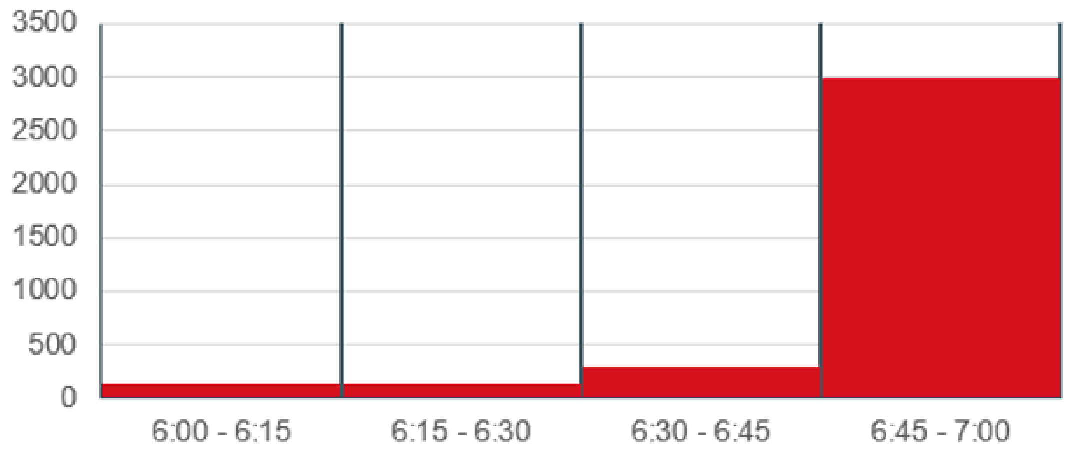

Figure 18 *The development of regulating price 22.1.2016 at 6.00 EET (Fingrid Oyj 2016)*

In the figure 18 the hour 6-7 of date 22.1.2016 is divided in quarters. In first three quarters the activation price of regulating power has not been significant. However, during the last 15 minutes the need for regulation increased and the price rose to 3000 €/MWh. Due to the time period of one hour, this 3000 €/MWh was the price for whole hour, even during three first quarters the regulating power was not that valuable. By the year 2021 there is changes expected for the time period of imbalance settlement as the Balancing guideline obligates that all TSO's should move into 15 minutes imbalance settlement period by three years after the Balancing Guidelines is entered into force (European Commission 2017b).

After the price is visible in real time in situations when system resources are scarce, it has to show the value of resources in scarcity situation. The extreme scarcity is the situation, where the TSO need to start shed the loads involuntary. Even during the surveyed time period 2013 – 2016 there has not been cases, where the load would have been shed involuntary, these situations can occur in future, and there should be an appropriate pricing mechanism to take care of these situations.

The third problem regards the pricing in the cases of special regulation, which is made for network reasons. As in Chapter 5 in table 3 was shown, the special regulation cases can also lead to situations where system resources can get scarce. The present pricing mechanism however leaves the price low and does not sent the signal for market participants that there would be need for system support. If the price signal is wanted to reflect scarcity also in special regulation cases, some changes need to be done regarding the treatment of special regulation.

The last flaw is that the present pricing mechanism principle sets the price to the last activated bid, which could be at maximum the price cap of regulating market. The current price cap for regulating market is 5000 €/MWh, which is lower than the most estimated assumptions for Value of Lost Load. The figure represents how the price would behave in hypothetical but possible case where the highest bid would be the cap price 5000 €/MWh and all the pre-contracted reserves would be needed and as the final solution, load would be shed. For the simplification there is an assumption made, that available pre-contracted reserves are equal to N-1 dimensioning. In reality also voluntary bids can ensure the N-1 for example in cases when there is maintenance breaks or other reasons that the capacity of pre-contracted capacity would not be enough to suffice N-1.

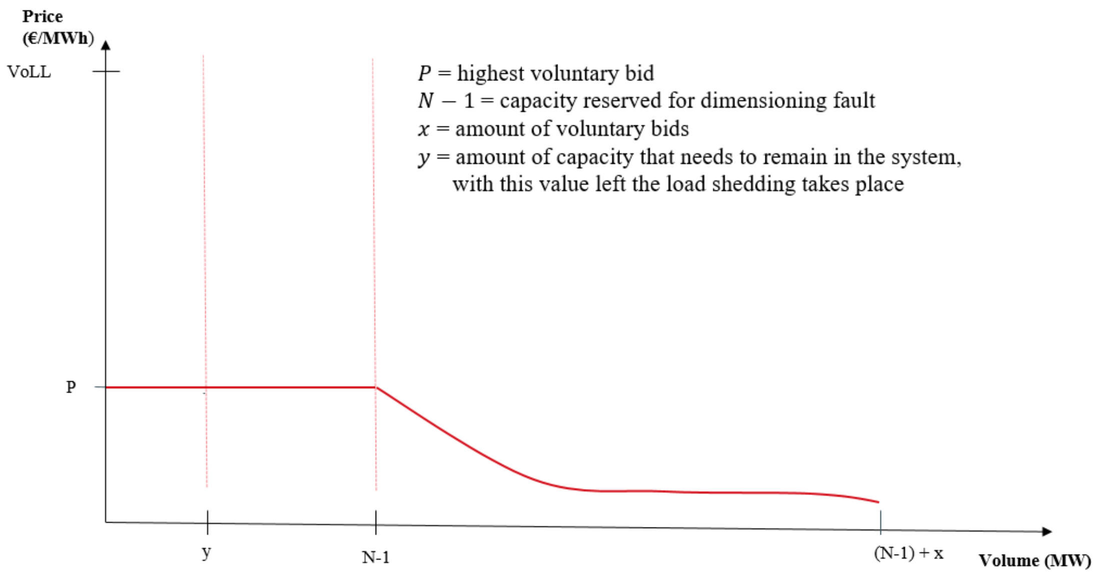

Figure 19 *Illustration of price development with present price forming in regulating markets.*

In Figure 19 the x-axis presents all the available volume for regulating. The volume is divided in x-axis such that from value 0 to N-1 is assumed to be the available volume from pre-contracted reserves and the volume x presents the sum of voluntary bids. The variable y represents the value, which needs to remain in system even if the load is shed. The red curve illustrates the possible price development presenting the price at the point where there is a certain value of regulating volume left. When there is more than N-1 MW left, the price P is determined by the merit order list and when the whole volume of x is used, the price is at the highest voluntary bid.

6.2 Improving scarcity pricing

The visibility to the prices and shorter imbalance settlement time period are necessary if we want to market participants to react to the price as close to real-time as possible. To make a suggestion and be able to assess impacts of scarcity prices we assume that these two circumstances exist. So the starting point is that the price development in scarcity situation is shown in real-time and the imbalance settlement and trading period of regulation market is set to be at maximum 15 minutes.

Here is also made an assumption, that the balance responsible parties are wanted to participate to the system balancing, not just maintain their own balance. To enable the participation, there should be incentives for balance responsible parties to respond to the price. This means that those balance responsible parties who in scarcity situation still have some resources, for example the possibility to decrease consumption or increase generation, should be remunerated for their actions and on the other side those who are worsening the situation or even have caused the situation should be financially responsible for the caused deficit through "polluters pay" principle.

The incentive problem mentioned above is partly already taken care with present imbalance settlement. As explained in chapter 3.4.1, participants having deficit imbalance need to buy afterwards the missing energy, which works as an incentive not to have deficit imbalance. However the other direction, only those with surplus in consumption imbalance are payed the regulating price, the surplus in production balance would get only the day-ahead price for their surplus that would have been supporting the system.

To provide better incentive for balance responsible parties in scarcity situation, it is assumed here that the imbalance settlement pricing would be a single pricing, where the balance responsible parties are remunerated also when their final position of production imbalance in the end of imbalance settlement period is surplus.

To improve the price development such, that it would take into account the VoLL one option would be simply to raise the price cap to the VoLL, which means that the maximum price for bids market participants are giving in regulating markets would be VoLL.

This is also the supported in Clean Energy package for all price caps including price caps in balancing markets (European Commission 2016).

Removing the price cap alone still do not guarantee, that the market participants would give bids with this price. Anticipating rare scarcity situations is not easy and there is no guidelines how participants should reflect scarcity in their bids (CREG 2016). As seen from analyses in chapter 5, there are cases in which all the market based bids are used, but the price cap is not hit. This might be the result of competition, the ones that would set their price to the level of Value of Lost Load might get their bid used really seldom. In energy-only market it can be hard for national regulator authorities to see the difference between use of market power and the scarcity pricing (CREG 2016) so also the fear of regulatory intervention could be one reason for not bidding with the prices near the set price cap.

As discussed above, it is not guaranteed, that the price of last activated voluntary based bid would hit the VoLL even if lower price caps would be removed. To ensure that the price would reach VoLL there might be need for administrative set the price to VoLL when the power system is in the situation that the TSO has to start to shed loads. This approach guarantee, that the VoLL valuation is not depend only on the bid behavior of participants. The price development with setting the price automatically to level of VoLL in case when load shedding occurs is illustrated in figure 20.

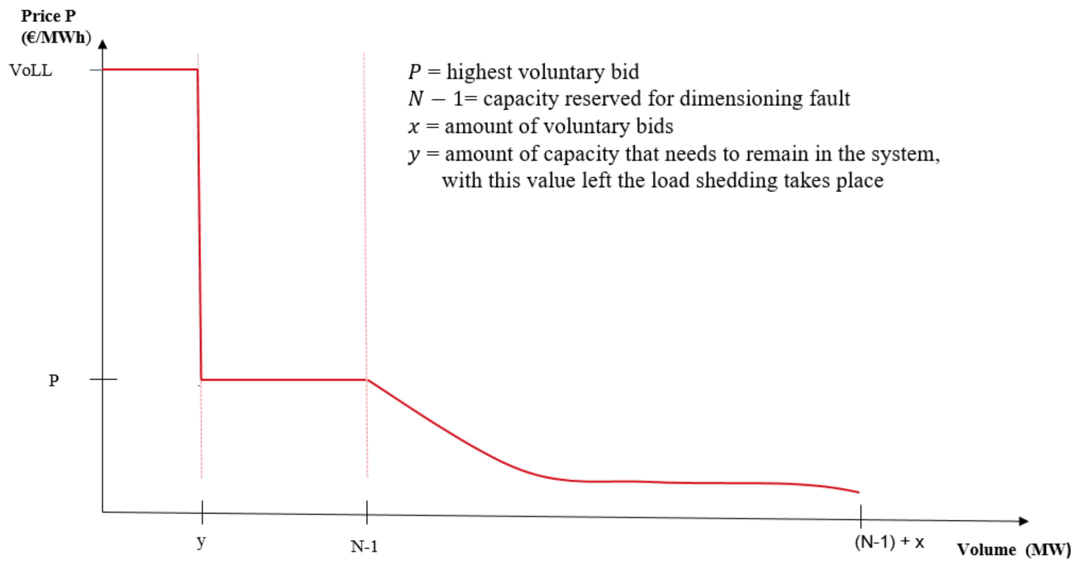

Figure 20 *The price is set to the VoLL when load shedding takes place.*

Even the price takes now into account the VoLL, the price is not developing when using the reserves pre-contracted by TSO. After all the voluntary based bids are used, the TSO still have pre-contracted reserve that can be used before the load need to be shed. This means that in power shortage situation TSO can compromise the N-1 rule and use the resources reserved for only disturbance purposes. The use of TSO owned or leased gas turbines is a hard to price from market principles, as these reserves are receiving a capacity compensation which costs are covered by tariffs that are allocated for all transmission grid users. However if the price is supposed to describe the usage of reserves, one option would be to introduce a scarcity adder that would take care of the price development in the area where the TSO owned fast disturbance reserves are used. This way the price change from P to VoLL in figure 20 would not be as steep and balance responsible parties could have time to respond to the price before price actually reaches VoLL.

The price development could be calculated with the approach of loss of load probability function following the idea explained in chapter 4.3. However to calculate different Loss of Load probability functions is out of the scope of this thesis, so we will simply assume the linear price curve between the area N-1 and y to illustrate the scarcity adder. This approach is shown in figure 21

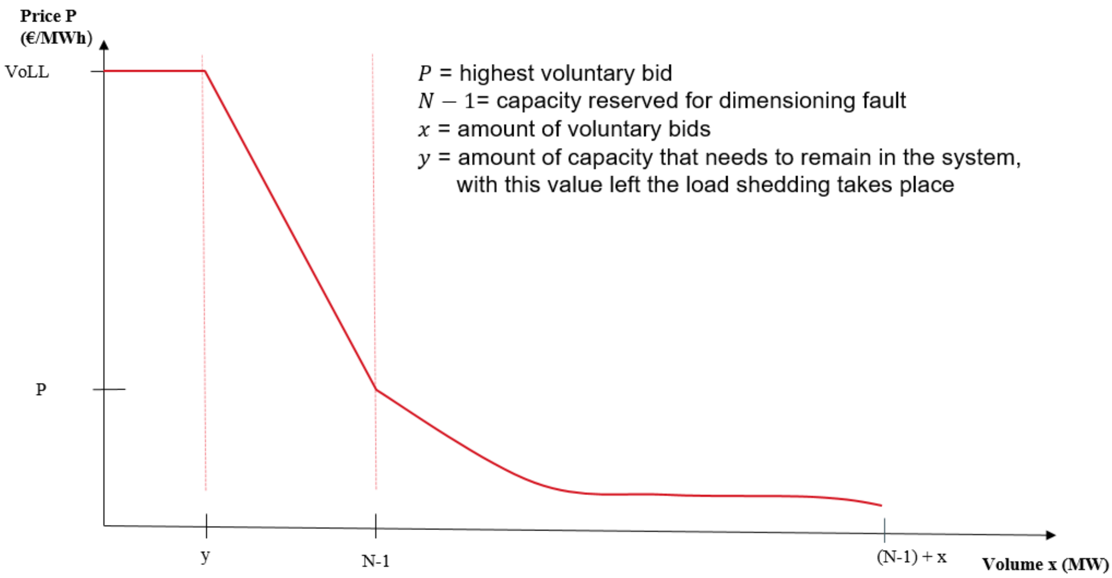

Figure 21 *The illustration of scarcity adder in the case when TSO need to compromise N-1 rule.*

Now there is a price formation that takes into account the Value of Lost Load and also develops the price when the pre-contracted reserves are used. Here the regulating capacity which is dimensioned regarding the N-1 rule was assumed to be pre-contracted reserves. However this kind of approach could be used also in cases when the N-1 rule is sufficed with voluntary bids keeping the rule such that always, when the N-1 rule is comprised, the scarcity adder is applied.

There is still need to think how the price signals that are not reflecting the value of scarce resources from special regulating cases could be overcome. One option could be starting to treat the special regulation cases with the same price formation rules as are followed for balance regulation. This means that the change from pay-as-bid principle to marginal pricing, which gives the regulation provider the same marginal price independent from the reason regulations are used.

Secondly there is need to think who this price should face. Currently the regulating price is faced by those participants that are providing the regulation as a payment they are receiving and also balance responsible parties that either do receive or pay this price for their imbalances. Costs regarding the regulating and imbalance settlement do also go through TSO. In next chapter the possible impacts of these proposed improvements are discussed.

6.3 Assessing impacts of scarcity pricing

In Chapter 6.2. the possible mechanism to form price in situations when the N-1 rule is compromised and when the possible involuntary load shedding takes place is developed. Now it should be defined in more detail which kind of impact the implementation of scarcity adder would bring to different stakeholders and which kind of market design aspects could be used with the adder.

The stakeholders that are affected for these possible changes are limited here to be transmission system operator, balance responsible parties and the market participant providing the voluntary regulating bids. These market participants further called Balance Service Providers (BSP). As often the costs or incomes these up-level stakeholders do face are reflected also to their customers, in order to find out which would be the whole social-economic impacts in society level, the choice of stakeholders should be brought to the wider level, but in the scope of this thesis the effects assessed are limited to these three actors.

In order to understand which kind of effects scarcity adder would have on stakeholders, it is beneficial to understand which kind of money and energy flows there is involved with regulating market and with imbalance settlement. If the scarcity situation occurs, the scarcity adder affects clearly to the price. The energy and money flows between the stakeholders regarding regulating market and imbalance settlement during up-regulating hour are illustrated in figure 22.

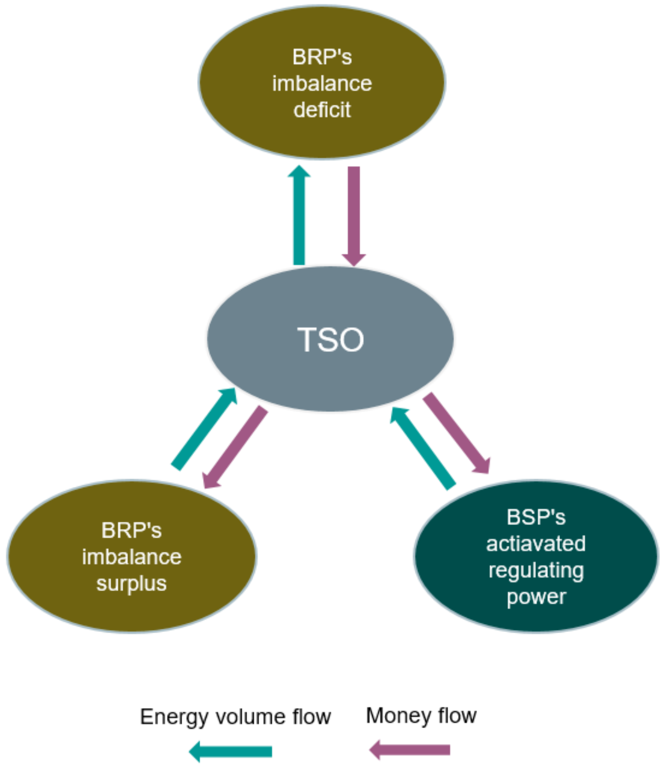

Figure 22 *Money and energy volume flows between stakeholders in up-regulation situations.*

The figure 22 can be assessed from the perspective of TSO. The costs for the TSO regarding the regulating market and imbalance settlement are following. TSO buys the activated regulating energy from balance service provider, which brings costs to TSO and again income for BSP. TSO is also committed to buy surplus energy from BSPs which brings costs to TSO and income for BRPs. The deficit energy again is sold to BRP, which means costs to BRP and income for TSO. Here to be specific, the actual body through which the money flows is eSett instead of Finnish TSO, but as the eSett is a service provider to Fingrid, for the simplicity TSO is considered here as receiver and remitter of money. To simplify the case further, we will consider the one-price model to be applied to both production and consumption imbalance, so we can handle the BRP's imbalance position as a one, the netted sum of the production and consumption imbalance which is either surplus or deficit.

We will discuss about two options for applying the scarcity adder. First option is to apply the scarcity adder with marginal pricing to both, to the regulating price and to imbalance price. This is the way as it is done presently and this would mean that in the cases when there is less regulating volume left than N-1, the scarcity adder would be applied and all the balance service providers including the activated pre-contracted resources would be paid price determined by scarcity adder and the imbalance price would be priced with the same price. Another case is, that scarcity adder would be applied only to the imbalance price, meaning that the balance service providers would get the marginal price determined by the last activated bid, but the imbalance price would be calculated such that the scarcity adder would be applied to its price.

The assumed main impacts of applying the scarcity adder regarding each stakeholder are collected to the table 5 below. These impacts are discussed more in detail in following chapters 6.3.1, 6.3.2 and 6.3.3.

Table 5 *Assumed main impacts of applying the scarcity adder in scarcity situations*

Stakeholder	Assumed impacts of the scarcity adder in scarcity situation
Balance Responsible Party	• Incentives to react to the price signal. • Opportunity to be remunerated when supporting the system brings value for BRP's flexible assets. • Risk of facing high imbalance costs incentives to avoid deficit imbalances.
Transmission System Operator	• Scarcity adder incentives available resources to participate in system balancing, which helps TSO's target of restoring the system balance. • May cause risk of oversized reaction from BRP's side and change the operational situation. • The possible incomes from scarcity adder can be allocated to the reserve costs, which moves the cost distribution towards the "polluter pays" principle.
Balance Service Provider	• In case when scarcity adder would be applied to both, regulating and imbalance price, the balance service providers would get a higher price for their activated bid. • In case when the scarcity adder would be applied only to imbalance price, there might occur optimization between giving the resource for regulating market and getting the remuneration from imbalance settlement.

6.3.1 Impacts on balance responsible party

The exact behavior of balance responsible parties is hard to predict. However the behavior can be outlined by assuming that balance responsible parties wish to avoid the costs of imbalance price they need to pay for being deficit and get the remuneration when it is allowed and possible.

For the role of balance responsible party there is no difference whether the scarcity adder is applied for both, the regulating and imbalance price or only to the imbalance price, as the price they are facing is the same in both options. To be specific, the balance responsible parties can also act as a balance service provider, which means that there is a link between these two roles and there can be synergism when the same company has these two roles. However here we will consider the balance responsible party only as a separate role and the optionality between these two different ways that scarcity adder could be applied is not discussed in this section.

Assuming a scarcity situation, where Finland is separated as its own regulating area and regulating reserves are such short that TSO has to compromise the N-1 rule. In this case the scarcity adder would be applied. The price would be visible, which means that BRPs have possibility to react to this price. In scarcity situation it would be beneficial to the system to get all spare resources from the BRP's to use, even it would mean for BRP to purposely not be on the balance but to have a surplus. In scarcity situation the high visible price gives a signal that incentives balance responsible parties who have a resource that is not taking part to the regulating market to help to support the total balance of the system. So those parties, who can offer some flexibility are remunerated. Then again, those balance responsible parties who have deficit imbalance during the scarcity moment, face high costs.

Even if the price would be higher than in similar situation with present pricing mechanism, it would not necessarily mean higher costs as the price would be set only for 15 minutes at a time and by visibility the BRP has possibility to react that price and improve its deficit position for next 15 minutes. Like this the scarcity adder would incentive BRPs to find new ways to to include flexible resources to their portfolio and also a strong incentive to avoid all kind of generation losses and forecast the consumption and production as accurate as possible.

Applying the scarcity adder also has risks. One possible risk is if BRPs start to reserve their generator capacity in fear of losing part of their generation and this way to hedge themselves from being deficit but also at the same time actually to contribute the creation of scarcity situation. For example, if the VoLL would be defined as 15 000 €/MWh, and if the present biggest generation unit in Finland, with net power of 880 MW trips from power system and the situation is such that it would escalate into scarcity situation where the price would be set to the VoLL, it would create following losses for 15 minutes

$$0{,}25\ h * 880\ MW * 15\ 000 \frac{€}{MWh} = 3{,}3\ M€. \tag{3}$$

This kind of losses are for sure wanted to be avoided, and the worst scenario is that BRPs do not start to find alternative solutions to find flexibility for their portfolio, but instead start to reserve generation to hedge against this kind of situations. However reserving energy that could be sold in day-ahead or intraday market also create lost money, as they reserved generation cannot participate to markets and produce incomes for participant.

One possible solution to avoid the unwanted behavior of reserving generation capacity is to develop other hedging mechanisms. Currently balance responsible parties have a possibility to trade in intraday market until 30 minutes (in Finland) and 60 minutes (in other countries of synchronous area) before the delivery hour. This means that if the generation is lost, there is possibility to purchase the energy of lost production from intraday markets for upcoming hours. The intraday market is an important hedging possibility for balance responsible parties and to develop it further and enable trading as close as possible the actual delivery time would help the BRPs to hedge against the risk of high imbalance cost. Another way could be developing the forward products for imbalance price hedging, which enables the balance responsible parties to contract the imbalance price beforehand and like this hedge themselves from the volatility of imbalance prices.

Another possible risk is that if this kind of incentive would decrease the resources from actual regulating market, as in scarcity situation the BRP could have same price from regulating market than from just doing the self-regulation according to the price signal. Even the remuneration in scarcity situation would be same as in the regulating market, the scarcity situations are hard to predict and rare. This makes the regulation market still more guaranteed market, as there the capacity has possibility to receive money also in situations which are not yet escalated to scarcity situation.

If the treatment of special regulation would be changed to be equal with the balance regulation, it would mean that the BRPs would be also informed about the price development and they would have an incentive to take part to supporting the system also in cases when the imbalance in system is not caused by them. This means that BRP's do also have a possibility to get remunerated or possibility to face risk of costs in cases when the origin of scarcity situation is in network faults or similar.

The visible price with scarcity adder also requires continuous observation and anticipation of situations and quick responses when the scarcity situation occurs. It is assumable that this observation and reactions to the price should be done automatically rather than by using human resources. This means that this kind of scarcity adder requires automation technology.

6.3.2 Impacts on TSO

In the scarcity situation, the visible price with scarcity adder would incentive all available resources to participate in system balancing, also those resources which are not taking part the regulating market. This would bring the possible benefit of reducing the risk of involuntary load shedding. However there is also a risk that the reaction to the scarcity price signal would be oversized, which means that the operational situation would change such that generation would exceed the demand and the power system would be in such situation that TSO needs to activate down-regulation bids. However, it is quite unlikely, that during a scarcity situation in system there would be that much available resources, that the reaction to the price signal would be significantly too great. And if the reaction to the price signal is excessive, it should be seen during next 15 minutes with decreasing price as there is not anymore need for all regulation bids. And one can assume that handling the momentary excess resources by activating down-regulating resources would be a cheaper solution than shedding the load.

The costs for TSO regarding regulating market and imbalance settlement are the remuneration paid to the balance service provider and costs from surplus imbalance of balance responsible parties. In the case, when the scarcity adder is applied to both, to the regulation price and to the imbalance price, these volumes that TSO purchases are bought with the price affected by scarcity adder. This means that the cost of such a situation do increase for TSO. However as in many cases the imbalance deficit is the reason for regulating, the volume of imbalance deficit should be roughly the same volume as a sum of volumes that TSO need to purchase from regulating market and volumes of imbalance surpluses that TSO need to purchase from balance responsible parties. And if we consider one-pricing model, the price for deficit imbalance is same as the price for regulating energy and surplus imbalances, which should make the net result for TSO near zero.

The situation described above is however idealized and all the money and energy just flows through the TSO leaving the net impact to be zero. In reality the sum of regulating bids and net surplus energy of balance responsible parties do not equal perfectly with the volume of deficit imbalance of balance responsible parties. One reason for that is the time unit which makes it possible for balance responsible party to net deficits and surpluses inside the time unit and the regulating and balancing power settlement done within the neighboring TSOs.

Because the imbalance settlement is not done in real-time, the balance responsible party can in theory have several positions inside the time unit, and these positions are netted when calculating the final position of balance responsible party. A hypothetical and simplified example will clarify that. Imbalance of balance responsible party can for the first half of time unit be deficit and create a need for up-regulating and the last half of the time unit the balance responsible party can have surplus the volume that equals the deficit of the first half of the time unit. This means that the final position of the balance responsible party can be zero and there is no any transaction between the TSO and the balance responsible party, but still TSO need to pay for the regulating energy which was activated because the first half of the time unit.

Another example case can be that Finland has activated up-regulating power, but the end position of Finland has been surplus and this surplus is then netted with neighboring TSOs. An example with the actual volumes from the one hour imbalance settlement will clarify this. On 2.2.2016 at 21.00 -22.00 the sum of up-regulating power activated in Finland was 197 MWh and no special regulations were activated. For this hour the imbalance of Finland was 39 MWh surplus. The up-regulating price in Finland was 65 €/MWh. If there would be a model that all the imbalances would be priced with a single price, this would mean from TSO's perspective that as a net Fingrid had netted costs from purchasing the regulating energy and the surpluses of balance responsible parties:

$$(197 + 39)\ MWh * 65 \frac{€}{MWh} = 15340\ €. \qquad (4)$$

The surplus of Finland is again settled with neighboring TSOs such that if Finland is surplus as in the case described above, Fingrid sells the surplus but with a price that is average of the regulating prices of the TSO's (ENTSO-E 2016a). As the price is an average price, in cases where prices between regulating areas are different, TSO sells the energy with different price it had purchased it, which further implies, that the net result is not actually a zero.

However, when assuming that the imbalance settlement period will change to the 15 minutes, it can be assumed that the effect of possible netting of imbalance positions will decrease as the time unit is shorter and we can assume here, that the sum of activated regulating power and balance responsible party's surplus is to the appropriate level equivalent to the deficit of balance responsible party within the 15 minutes time unit, which would mean that the costs of scarcity adder would be close to neutral for TSO.

In the case, when scarcity adder would be applied only for imbalance prices and the regulating price would be set by the price of last activated bid, TSO would pay less for regulating than with the scarcity adder. If we assume that activated regulating energy and net surplus of BRPs' equals the net deficit of BRPs', the TSO would get surplus with incomes as TSO needs to pay less for purchasing energy than it sells the same volume of energy.

In both cases, in the case with scarcity price applied only to the imbalance price and to the both regulating price and imbalance price, the TSO has possibility to get net income. This could bring the impact of different distribution of costs for pre-contracted capacity. At the moment the costs of balancing capacity market and the gas turbines owned or leased by Fingrid are covered by grid and balance service tariffs. This means that costs are allocated to all grid and balance service users instead of those who are originating the imbalances that causes the need for these reserves. With the scarcity adder the pre-contracted capacity would also get the revenue with marginal pricing and revenues that the pre-contracted capacity get could be used to cover the costs of pre-contracted capacity. This means that the cost distribution could be moved more towards the "polluter pays" –

principle than allocating the costs of pre-contracted capacity to all grid users. This however is also a question of the philosophy of the reserves that are reserved for guaranteeing the security of supply, are they a public good that everyone should pay as the result of not having these reserves could randomly affect to everyone's life. Or should that player who is causing the imbalance in power system be responsible for that and also contribute more for costs for reserves.

If the special regulation would be changed to follow the same rules as regulation used for balance imbalances, it would mean moving from pay-as-bid principle to the marginal pricing. This would bring more costs to the TSO as if the cause of imbalance is not because of balance responsible parties, the TSO does not get the money paid to the surpluses and regulations back from those balance responsible parties that are deficit. To change the special regulation so would mean to the TSO would kind of be treated as a balance responsible party that is responsible for the imbalances that are caused because of network reasons. This would give strong financial incentive to avoid all kind of network interruptions.

6.3.3 The impacts on balance service provider

In the case with scarcity adder applied to regulating price, the balance service provider would be affected by getting the remuneration of activated bid with the scarcity price, which would be greater than with the present price forming system. This would be seen as an incentive to give the bids to the regulating market. The regulating market also provides the market place, where resources can get remuneration also in cases when there is no scarcity situation.

In cases where the scarcity adder would be applied only to the imbalance price, in scarcity situations the balance service providers would get only the price of last activated bid. Balance service providers and balance responsible parties do have a strong link, as the balance service provider can either be market participant, which production and consumption are in imbalance settlement allocated to some balance responsible party, or even in some cases the service provider and balance responsible party can be the same operator, only having a different roles. In scarcity cases when surplus imbalance can bring the better profit than providing the resource to the regulating market might bring an optimization between these two cases. However the regulating market is still more guaranteed place to sell the resources, as the resource can be used and remunerated also in other cases than in scarcity situations.

7. CONCLUSIONS AND DISCUSSION

This thesis discusses about the scarcity pricing in electricity markets, how it is understood and applied in other publications, and further this thesis aims to open a discussion how scarcity pricing could be applied in Finnish context. To understand better the factors that create situations with scarce up-regulating resources and how often these situations occur, this thesis surveys within a time period of 2013- 2016 the usage of regulating market bids provided by Finnish market participants and further the price signals that the occurred scarcity situations have resulted in. This thesis also takes a deeper look in the present formation of regulating and imbalance price formation in Finland in order to find out, what are the reasons that the prices do not reflect the value of scarce resource and take into account the resource valuation of consumers. This thesis also gives proposals, how the present price forming of regulating and imbalance price could be improved in order to enable better scarcity pricing.

During the time interval surveyed, there was altogether 18 hours, when 90 % or more of voluntary up-regulation bids that are getting their remuneration only for energy activated were used for regulating. For six hours out of these 18 situations there was an UMM given regarding the unplanned unavailability of production. Another six cases again were linked with UMM regarding unplanned unavailability of interconnector and most of the bids during these hours were used for network management and marked as special regulation. During most of the hours Finland was separated as its own regulating area, so during these hours the regulating resources of neighboring Nordic TSOs' could not be used and Finland was separated as its own regulating area. Also in 12 out of 18 cases the availability of voluntary bids was less than the average and median of the corresponding year. From these results it can be concluded that scarcity situations are most likely to occur when a significant component, either production or interconnector trips from the network at the same time when the availability of voluntary bids in regulating market is low.

From these 18 detected hours, during the situations when there was no special regulation involved the up-regulation price rose clearly over their average price level. Also the imbalance price which is conducted from the up-regulation price during up-regulation hours was clearly higher than its' average price. The highest up-regulating price and the corresponding imbalance price detected was 3000 €/MWh, but none of the hours did result in the present price cap of 5000 €/MWh. During the hours involved with special regulation, the up-regulating and imbalance prices stayed at the same level as day-ahead price for corresponding hour, meaning that the up-regulating price does not give the signal of regulating resources to be short.

Between years 2013 – 2016 no cases with extreme scarcity situation with involuntary load shedding was detected. Even there was not such a case during the surveyed time interval, there should be a price formation for regulating price and imbalance price, which in these cases would reflect the scarce resource. However the present price formation practices in regulating market and imbalance settlement include flaws that prevents the price signal from reflecting the scarcity situations. The hindered price signal again do not give sufficient incentive for market participants to participate in supporting the power system in scarcity situations.

When the resources in power system are scarce, the price signal should be visible in real time. There has already been improvement for this as Fingrid launched a pilot in November 2016 to publish the up-regulating price when there is only 100 MW of voluntary bids left, Fingrid publishes the present regulation price. Besides the visibility, the regulation and imbalance price should reflect as close as possible the real-time conditions of the power system. The present period of hour is too long, but in the future the change to 15 minutes imbalance settlement period will help to overcome this flaw. These two changes, visibility and shorter imbalance settlement period will already bring improvements to enable scarcity pricing.

Present price formation is not taking into account the consumer preferences which can be in case when TSO needs to shed load estimated with the VoLL. VoLL reflects the value that customers are willing to pay for continuous electricity supply. To include the VoLL in the price formation, the present price cap of 5000 €/MWh should be set to the VoLL. However as it is not guaranteed that market participants would give bids with price of VoLL, it should be administrative ensured that in cases when TSO needs to disconnect load the price should be set to the VoLL.

In addition for cases when the power system is compromising the N-1 rule, there should be pricing that ensures that that the price is developed further from the last activated bid. In this thesis the price formation was illustrated with the linear curve that sets the price between the VoLL and last activated voluntary bid when resources meant to ensure N-1 rule are exploited. However the price formation in N-1 area should be further researched and for example the parameters to define Loss of Load Probability function would be a good approach to set the price when comprising the N-1 rule.

Another problem with present regulating market and imbalance settlement design is the handling of special regulations, which are regulations that are normally done for network reasons. Problems that are originated from faults and interruptions of interconnectors between neighboring TSOs can also create shortage situations. If all situations where resources are scarce should give a signal to the markets showing that the regulating resources are scarce, there should also be a price signal from special regulation. With present practices the purchase of energy used for special regulation is prices in accordance with the bid activated and is not affecting imbalance price. If balance responsible parties are wanted to participate the system balancing also in cases when network problems are causing the scarcity situation, the marginal price of regulation should be shown at least in imbalance price. If the marginal pricing would be applied instead of pay-as-bid price, it would mean more balancing costs for TSO if TSO need to do special regulation. However this could also be seen as a stronger incentive for TSOs to avoid faults and interruptions of interconnectors.

As a possible impact scarcity adder would bring the stronger price signal to balance responsible parties. The visible and real-time scarcities reflecting price can as its best incentive those balance responsible parties who are not taking part the regulating market but have flexibility to help supporting the system in scarcity situation. In scarcity situation the balance responsible party that can support the power system with flexible resources is remunerated with the price that reflects the scarcity for providing the resource. And those balance responsible parties that are contributing the scarcity situation by having a deficit imbalance are facing the imbalance costs. So scarcity adder in first place does incentive not to create deficit imbalance and be surplus in those cases when it is needed action from systems perspective.

The exact behavior of market participants is hard to anticipate. The positive effect of scarcity adder would be that balance responsible parties would find alternative solutions to add flexible resources in their own electricity purchase and consumption portfolio, to answer the scarcity situations. However there is also a risk that market participants starts to reserve their own production and this way also contributing to the scarcity situation to occur. To be able to avoid this kind of risk different hedging mechanism should be discussed. These hedging mechanisms could be for example developing trading possibilities in intraday market. Market participants could also develop financial hedging products that could hedge the balance responsible parties from the imbalance price.

The implementation of scarcity adder and changes in design of regulating and imbalance price formation can bring positive effects as it would incentive the balance responsible parties to take an active role in scarcity situations to balance the power system. However the proposals presented in this thesis need further development and discuss before they could be implemented in practice.

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