Design Principles of the Future Balancing Philosophy in the Finnish Power System

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Abstract of the master's thesis

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Abstract

The Nordic synchronous power system has come to a situation in which the operational security is challenged due to the reformation of the power system, which especially concerns the electricity production palette. In addition, European regulation has set demanding requirements with tight deadlines for the European TSOs regarding system operation and balancing. In order to tackle the challenges and to comply with the regulatory obligations, the Nordic TSOs have concluded a cooperation agreement, which defines the roles and responsibilities of the TSOs concerning the future Nordic balancing cooperation. The upcoming modifications, which relate to market solutions and power balance management, engender questions on how the changes affect the Finnish power system balancing and how the system should be balanced in the future.

This thesis includes a literature review and an empirical research. The literature review creates an overview of the current Nordic power system balancing. In addition, it introduces the key elements of the future Nordic balancing cooperation. The empirical part analyses quantitatively and qualitatively the influences of the upcoming changes on the power system balancing and whether the changes promote proactive or reactive balancing design.

According to the findings, Fingrid should exercise reactive power system balancing in the future. The upcoming changes will increase the responsibility of the market participants to control their own balance in a more accurate manner closer to real time. In addition, various forecasts and plans related to the forthcoming balancing periods are likely to become less reliable in the future, which shakes the foundations of proactive balancing performed by Fingrid. Thus, proactive balancing actions of the TSO could result in flawed outcomes and inefficient balancing performance due to, for instance, counter activations. Furthermore, some examples within EU area have shown that the introduction of reactive balancing design is likely to reduce the volume of system imbalances and the amount of balancing product activations. Despite the benefits, reactive balancing requires further research from the congestion management point of view as power grid conditions may set limitations on the balancing design.

Keywords Nordic power system, power system balancing, proactive balancing, reactive balancing

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Tiivistelmä

Pohjoismainen synkronijärjestelmä on tullut tilanteeseen, jossa järjestelmän käyttövarmuus on haasteiden edessä sähköjärjestelmässä tapahtuvien muutosten, etenkin tuotantorakenteen uudistuksen, seurauksena. Lisäksi eurooppalainen lainsäädäntö on asettanut vaativia tavoitteita kireillä käyttönottoaikatauluilla eurooppalaisille kantaverkkoyhtiöille. Selviytyäkseen haasteista ja noudattaakseen eurooppalaista lainsäädäntöä pohjoismaiset kantaverkkoyhtiöt ovat solmineet yhteistyösopimuksen tulevasta pohjoismaisesta tasehallinnasta. Sopimus määrittelee pohjoismaisten kantaverkkoyhtiöiden tehtävät ja velvoitteet sähköjärjestelmän tasapainottamiseen ja yhteistoimintaan liittyen. Tulevat muutokset, jotka koskevat markkinaratkaisuja ja tasehallintaa, synnyttävät kysymyksiä siitä, miten muutokset vaikuttavat Suomen sähköjärjestelmän tasehallintaan ja miten tasapainottaminen tulisi tulevaisuudessa hoitaa.

Tämä diplomityö koostuu kirjallisuuskatsauksesta ja empiirisestä tutkimuksesta. Kirjallisuuskatsaus luo kokonaiskuvan siitä, miten sähköjärjestelmän tasapainottaminen nykyisin hoidetaan Pohjoismaissa. Lisäksi se tuo esille keskeisimmät muutokset, joita pohjoismaisen tasehallinnan ja yhteistoiminnan tulevaisuuteen liittyy. Empiirinen osuus tutkii kvantitatiivisesti ja kvalitatiivisesti tulevien muutosten vaikutusta sähköjärjestelmän tasapainottamiseen ja tukevatko muutokset proaktiivista vai reaktiivista säätötapaa.

Työn tulosten mukaan Fingridin tulisi toteuttaa reaktiivista sähköjärjestelmän tasapainotusta tulevaisuudessa. Tulevat muutokset kasvattavat markkinaosapuolten vastuuta kontrolloida omaa tasetta tarkemmin lähempänä käyttöhetkeä. Lisäksi ennusteet ja suunnitelmat, jotka liittyvät tulevien tasapainotusjaksojen ennakointiin, ovat todennäköisesti epäluotettavampia tulevaisuudessa, mikä heikentää Fingridin toteuttaman proaktiivisen säätötavan lähtökohtia. Sen vuoksi kantaverkkoyhtiön toteuttama ennakoiva säätötapa voi johtaa virheellisiin lopputuloksiin ja heikentää tasapainotuksen suorituskykyä esimerkiksi vastasäädöistä johtuen. Lisäksi esimerkit EU:n alueella ovat osoittaneet, että reaktiivisen säätötavan käyttöönotto todennäköisesti vähentää sekä sähköjärjestelmän tasepoikkeamia että säätöä varten akti-voidun energian määrää. Hyödyistä huolimatta reaktiivinen säätötapa tarvitsee vielä lisätutkimusta verkon hallinnan näkökulmasta, sillä sähköverkon tilan huomioiminen voi asettaa rajoitteita säätötavalle.

Avainsanat Pohjoismainen sähköjärjestelmä, sähköjärjestelmän tasapainottaminen, proaktiivinen säätö, reaktiivinen säätö

Preface

This thesis was written at Market Solutions unit of Fingrid Oyj. I want to thank my advisor M.Sc. Mikko Heikkilä from Fingrid Oyj for the guidance and trust throughout the writing process. I would also like to express my gratitude to Professor Sanna Syri from Aalto University for supervising the thesis and keeping the process clear and simple. To all the people at Fingrid Oyj: Thank you for open and fruitful discussion and encouraging atmosphere.

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Contents

Abbreviations

ACE	Area Control Error
aFRR	Automatic Frequency Restoration Reserve
AGC	Automatic Generation Control
AOF	Activation Optimization Function
BEGCT	Balancing Energy Gate Closure Time
BRP	Balance Responsible Party
BSP	Balance Service Provider
CET	Central European Time
CMOL	Common Merit Order List
DSO	Distribution System Operator
EBGL	Electricity Balancing Guideline
FAT	Full Activation Time
FCR	Frequency Containment Reserve
FCR-D	Frequency Containment Reserve (Disturbances)
FCR-N	Frequency Containment Reserve (Normal)
FRCE	Frequency Restoration Control Error
FRE	Finland-Russia Exchange
HVDC	High Voltage Direct Current
ISP	Imbalance Settlement Period
LFC	Load Frequency Control
LMOL	Local Merit Order List
mFRR	Manual Frequency Restoration Reserve
MGA	Metering Grid Area
MTU	Market Time Unit
NERC	North American Reliability Council
NOIS	Nordic Operational Information System
SCADA	Supervisory Control and Data Acquisition
SGU	Significant Grid User
SOA	System Operation Agreement
SOGL	System Operation
TSO	Transmission System Operator
TSO GCT	Transmission System Operator Gate Closure Time
vRES	Variable Renewable Energy Source

1 Introduction

1.1 Background and purpose of the thesis

The Nordic power system is synchronously interconnected, which means that the power system area shares a common frequency and therefore, a change of power at one point has an influence on the frequency and power flow in the entire system (Statnett et al. 2016). The Nordic synchronous system is divided into four subsystems, which are divided further into 11 bidding areas as presented in figure 1 below. Each subsystem has an appointed transmission system operator (TSO): Energinet.dk for the Danish subsystem, Fingrid for the Finnish subsystem, Statnett for the Norwegian subsystem and Svenska Kraftnät for the Swedish subsystem. (ENTSO-E 2006)

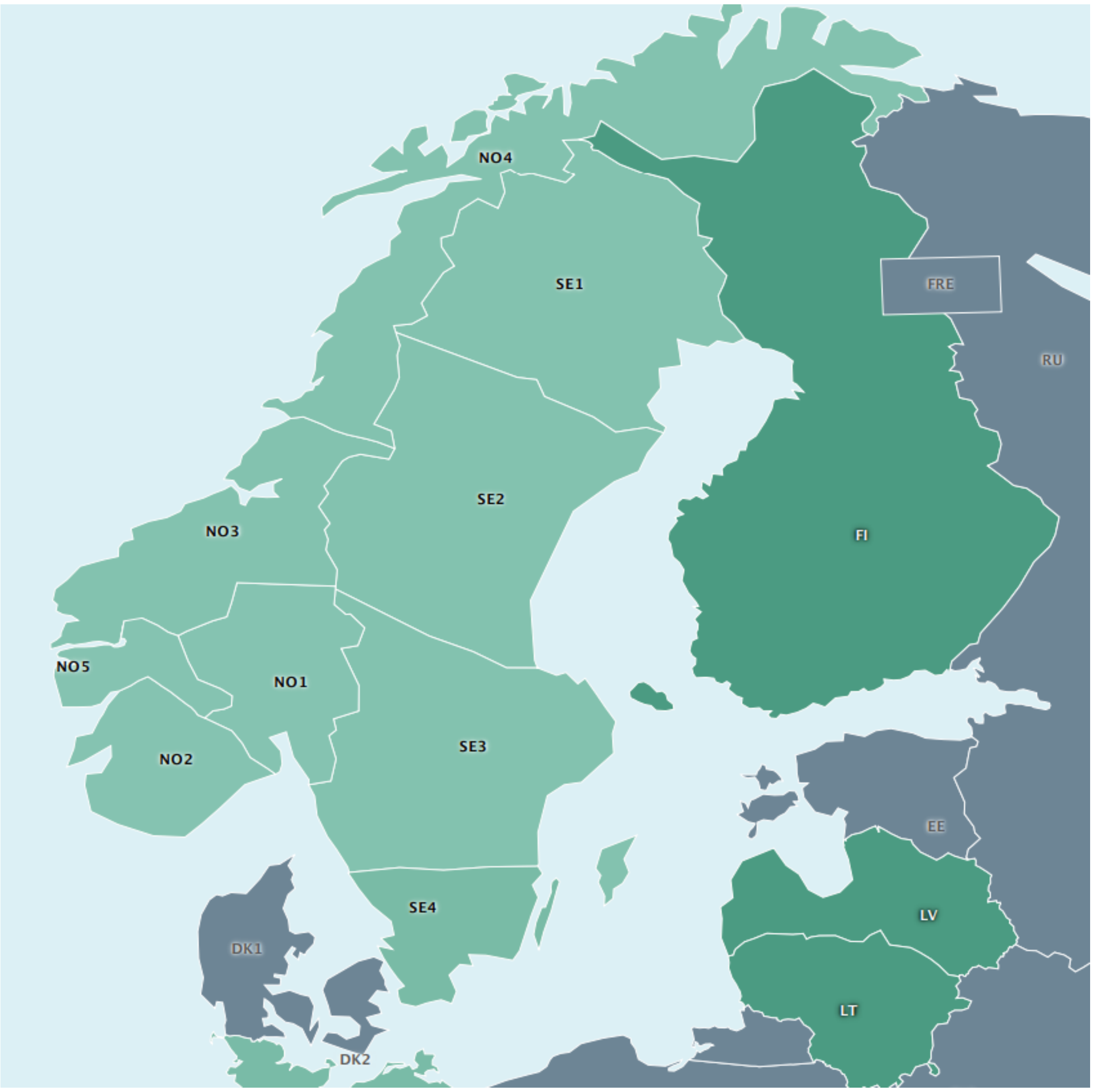


Figure 1: The Nordic synchronous power system consists of 11 bidding areas that are FI, SE 1-4, NO 1-5 and DK2 (Nord Pool 2019a).

Transmission system operators are responsible for the reliable power system operations and frequency control by maintaining power balance between electricity production and consumption (Scherer 2016). Since there are four different TSOs operating in the Nordic synchronous power system area, a cooperation between the parties has been a necessity in order to fulfill the responsibilities reasonably. Accordingly, the Nordic TSOs have a long collaboration history concerning various tasks related to the power system operations, planning and market solutions. (Statnett et al. 2016) Now the Nordic synchronous system has come to a situation in which the operational security of the whole system is challenged. The underlying reason is the reformation of the electricity production palette in order to mitigate climate change and the increment in the capacity of high-voltage direct current (HVDC) interconnectors. Along with these aspects, the European regulation including the guideline of electricity transmission system operation (SOGL) and the guideline for electricity balancing (EBGL) has set requirements and obligations with demanding deadlines for the TSOs. (Affärverket Svenska kraftnät et al. 2018) In order to tackle the challenges and to comply with the European regulation, the Nordic transmission system operators have concluded a cooperation agreement, which defines the roles and responsibilities of the TSOs related to the future Nordic balancing cooperation. In addition, the TSOs have created an implementation roadmap for the development of Nordic power system balancing. (Svenska Kraftnät et al. 2019)

The upcoming changes related to the Nordic balancing will increase the operational responsibility of the Nordic TSOs. Each TSO will be more responsible for maintaining power balance in their own control area. In addition, the utilization of market based solutions and price signals originating from them shall be increased. (Affärverket Svenska kraftnät et al. 2018) There are no former studies or papers discussing how the Finnish power system balancing should be managed and what kind of balancing strategy and philosophy should Fingrid follow in the future. Therefore, this thesis will answer to the following questions:

- What are the implications of the upcoming changes for the balancing design of the Finnish power system?
- Should Fingrid promote proactive or reactive balancing design?
- What are the reasons for the design choice and what are the aspects that require further research?

This thesis puts together several changes that relates to the development of the Nordic power system balancing. It focuses on the market and balancing perspectives without giving much weight to the network conditions that limit the operations, such as power grid congestions. Congestion management would have been rather large and separate perspective in this thesis, but it definitely requires further consideration in some other paper. The conclusions and recommendations that are given in this thesis can work as a basis for further discussion related to the balancing philosophy of the Finnish power system.

1.2 Content and structure of the thesis

The thesis starts by introducing the background and purpose and the content and structure of the thesis in the first chapter. In the same chapter, the regulatory framework is introduced, since the European energy policy, reflected in the regulation, is one of the key driving forces changing the balancing operations of the power systems within EU area.

The second chapter clarifies how the current balancing of the Nordic power system is executed. The chapter introduces basic principles of imbalances, how the imbalances are taken care of and what kind of balancing structure and products are required in the Nordics. In addition, imbalance settlement is discussed more closely as it is a major contributor influencing on the behavior of the balance responsible parties (BRP).

The third chapter deals with the future of the Nordic power system balancing in order to clarify what are the changes that shape the responsibilities and processes of the Nordic TSOs. The chapter introduces the key elements of the Nordic balancing development, fundamentals of area control error (ACE) based balancing, imbalance prognosis model and the European balancing market platforms that affect the development process via defining balancing product specifications.

The fourth chapter analyses how the upcoming changes affect the balancing design and philosophy of Fingrid. There are altogether four perspectives and design principles considered: market solutions, usability of production plans, availability of frequency restoration reserves and economic optimization.

The fifth chapter summarizes the conclusions of this thesis in order to answer the research questions. In addition, the chapter includes recommendations that are based on the findings of this thesis. Furthermore, a few topics related to the future work and further research are highlighted.

Chapters one, two and three are based on a literature review, which aims to provide a sufficient amount of information about the current and future state of the Nordic power system balancing to the reader. The fourth chapter is based on new and original experimental work: Various data analyses are carried out and some of the findings and deductions are supported by former research papers. The fifth chapter puts together the findings and conclusion that arise from the literature review and the experimental work. The references used in this thesis are mainly TSO publications, different regulation documents and peer-reviewed journal articles. Especially the latter two can be considered as papers of a good quality. The data analyses are based on data that is retrieved from Fingrid's open data website, Fingrid's internal IT-systems and Nord Pool's market data website.

1.3 Regulatory framework

This thesis is interested in the regulatory framework, since it sets requirements and implementation deadlines for the European transmission system operators regarding system operations and balancing. In this thesis there are several parts in which the regulatory context is brought out and therefore, it is important to consider the ultimate purpose of the European regulation, particularly system operation guideline (SOGL) and electricity balancing guideline (EBGL).

The system operation guideline (SOGL) relates to the European commission regulation and it entered into force in mid-2017. One of its main objective is to harmonize the rules concerning system operation carried out by the transmission system operators (TSO), distribution system operators (DSO) and significant grid users (SGU). The harmonization aims to result in a clear legal framework for system operation and ease the trading of electricity within the European Union and across the member states. Along with these aspects, the SOGL tries to ensure the availability and exchange of relevant data between the stakeholders that are involved in the system operation. Overall, the guideline improves the efficient use of the network and increases competition, which benefits the consumers and ensures system security while the integration of renewable energy sources continues to grow. (EUR-lex 2019a)

In addition to the system operation guideline, there exists an electricity balancing guideline (EBGL), which also facilitates the development of fully functioning and interconnected internal energy market within EU area. The EBGL entered into force at the end of 2017 and it sets various rules and requirements concerning balancing. The guideline defines the common principles for the procurement, activation and settlement of frequency containment, frequency restoration and replacement reserves. Efficient balancing rules aim to create appropriate incentives for the market participants so that they will help the system with the imbalance and scarcity mitigation. Such a well-functioning market should promote more efficient use of energy and additionally, encourage the producers to invest in new production facilities, especially generation units that produce electricity from renewable energy sources. (EUR-lex 2019b)

2 Current balancing of the Nordic power system

2.1 Framework for balancing

Electric power systems are complex networks consisting of electrical appliances that are owned and operated by several different parties in order to enable production, transmission, distribution and consumption of electricity. Power systems are prone to imbalances due to the mismatch between electricity production and consumption, which is one of the major challenges related to the power system stability and control. Equation 1 below exemplifies how the imbalances arise: If the sum of consumption and losses is greater than the production, there exists an electricity deficit in the power system. If the sum is less than the production, there exists an electricity surplus.

$$Imbalance = Production - Consumption - Losses \tag{1}$$

The Nordic power system includes various producers and consumers, which generate and utilize varying amounts of electricity according to their interests. Thus, there is a need for processes that enable electricity exchanges and price formation for these exchanges so that different stakeholders with different necessities can trade electricity with each other. Electricity trading was remarkably influenced by the European electricity market liberalization, which was launched in the middle of the 1990s. It unbundled the electricity generation and distribution ownerships and businesses and created competitive markets for electricity sales in order to allow consumers to buy electricity from any supplier they want regardless the geographical location. (Partanen et al. 2015)

In the wholesale markets electricity trading takes place between large-scale market participants that are electricity consumers, electricity producers, traders and retailers, which procure electricity in order to fulfill the electricity demand of their retail market customers (Partanen et al. 2015). Market participants that are eventually responsible for balancing load and generation portfolios are referred to as balance responsible parties (BRPs) and all the physical connection points are linked to them (Hirth & Ziegenhagen 2015).

The common liberalized wholesale market for electricity in the Northern European area includes Denmark, Estonia, Finland, Norway, Lithuania, Latvia and Sweden. The wholesale marketplace for financial products is Nasdaq OMX Commodities and the power exchange is currently Nord Pool in which majority of the physical power is traded. (Boomsma et al. 2014; Partanen et al. 2015). However, European regulation that has recently come into force allows multiple power exchanges to operate in one bidding zone (Emissions-EUTS.com 2019a). Thus, there may exist other power exchanges in addition to Nord Pool in the Nordics in the future. Nord Pool provides day-ahead and intraday markets to the market participants: Day-ahead market is the main marketplace for trading power and there contracts are made between buyers and sellers regarding the electricity that will be delivered on an hourly basis the following day. Deadline for submitting bids is 12:00 CET and the power contracts are physically delivered beginning from 00:00 CET covering all the hours of the next day. (Nord Pool 2019b) Intraday market supplements the day-ahead market by enabling trading closer to real time. It is a continuous market meaning that trading takes place round the clock every day after the day-ahead market closure. The intraday market closes one hour before the period of operation and it allows the market participants to trade electricity after the day-ahead market closure. It should be separately noted, that the intraday gate closure time is exceptionally 30 minutes in Finland and between the border of Finland and Estonia. (Nord Pool 2019c)

Actions and bids of the market participants are driven by planning and forecasting. Before sellers submit bids, they need to assess and decide how much electrical energy they are capable of delivering and at what price. On the other hand, before buyers submit bids, they must consider the volume that is required to meet their future electricity demand. (Nord Pool 2019b) Thus, the day-ahead and intraday markets can be seen as balancing tools to ensure power system balance by setting predicted supply and demand in equilibrium. However, transactional balance may not result in flawless physical balance due to forecast errors and unforeseen events causing loss of production or consumption, such as power plant trips.

In addition to the above-mentioned stochastic occurrences, power system imbalances follow from the behavior of the market participants, since the actual production and consumption patterns may differ from the forecasted and scheduled positions during the operating hour (Copenhagen Economics 2017). For instance, a large electricity consumer can procure 10 MWh of electricity from the power exchange meaning that it should consume energy at an average power rate of 10 MW for an hour. However, the consumer can deviate from the average power rate. In the beginning of the period, it can consume energy at lower rate and in the end at higher rate. On the other hand, the producer that should supply the demand can deviate from the scheduled position due to, for example, power facility ramping requirements at hour shifts (Hirst & Kirby 1996). The positive and negative deviations can net out over the one-hour period of examination, which means that real time power system imbalances can take place, although the electricity trades can match up perfectly with the physical electricity deliveries over the hour period (Copenhagen Economics 2017). Figure 2 below represents the netting out of production deviations in the morning of January 16, 2019. The black line shows the actual production in Finland between 07:00 – 08:00. The red line is the average production, which can be considered as the scheduled and forecasted production for that hour. The gray area is negative deviation and the blue area is positive deviation. Since they are equally sized, energy will net out and thus, the scheduled position is perfectly accurate over the hour.

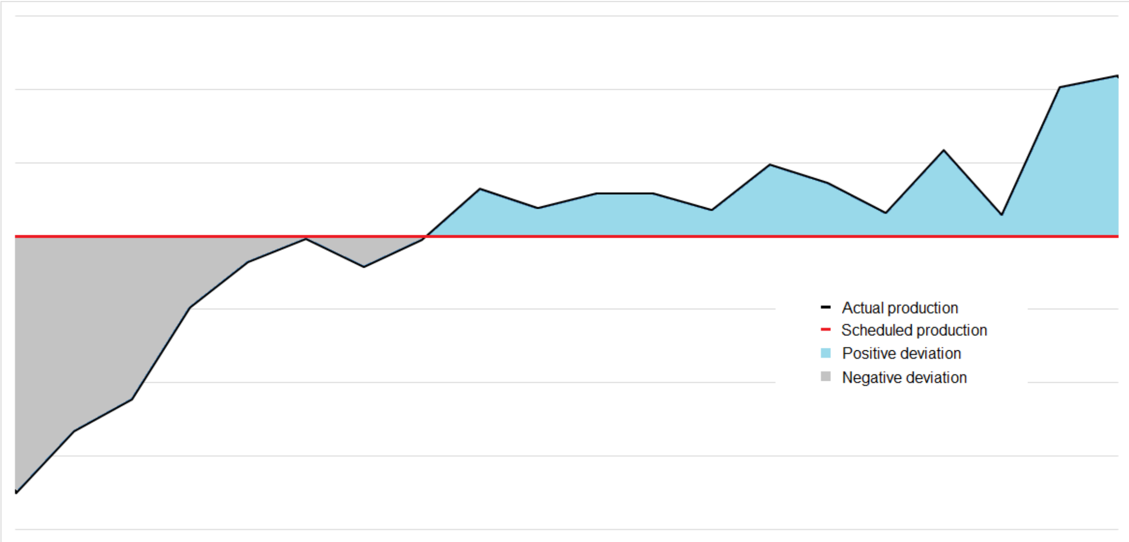


Figure 2: Netting out of deviations between actual production and scheduled production between 07:00 – 08:00 in the morning of January 16, 2019.

Because of the physical and organizational structure, the Nordic power system is prone to imbalances. If the production and consumption patterns were accurately predictable and all the possible changes were deterministic, there would not appear imbalances during the real time system operation (Scherer 2016). It is noteworthy that the power system frequency is dependent on the real time imbalances: It increases due to electricity surplus and decreases due to electricity deficit. For stable system operation, the frequency should be kept nearly constant by restraining imbalances. Additionally, the frequency is common throughout the system: A change in production or consumption at one point affects the frequency of the whole system. Major frequency drops can cause high magnetizing currents in the grid-connected appliances, such as generators and transformers, and may result in equipment damages and, ultimately, blackouts. (Kundur 1994) Thus, the frequency and imbalances of the power system must be controlled in real time in order to prevent severe system failures that could even lead up to societal inefficiencies.

The real time control of the power system frequency needs ancillary services (Scherer 2016). In a paper that deals with electric-power ancillary services, Hirst & Kirby (1996) bring out a definition of ancillary services as “those services necessary to support the transmission of electric power from seller to purchaser given the obligations of control areas and transmitting utilities within those control areas to maintain reliable operations of the interconnected transmission system.” The frequency control and ancillary services should be taken care of by transmission system operators (TSO) as they are responsible for the reliable power system operations (Scherer 2016). In practice, the respective TSOs activate balancing power, if the sum of BRP imbalances differ from zero (Hirth & Ziegenhagen 2015). In order to do so, there is a need for associated generation or controllable load resources that, however, cannot be owned by the TSOs due to the market liberalization. Thus, the acquisition of those resources usually follow market-based mechanisms. (Scherer 2016)

As there are four different TSOs operating in the Nordic synchronous power system, a system operation agreement (SOA) is needed to control the operations between the TSOs and to guide the cooperation in order to ensure fluent control of the common synchronous power system (ENTSO-E 2006). The Nordic SOA clarifies the responsibilities of the TSOs. After the intraday market closure and during the operational hour, balancing of the Nordic power system is the responsibility of the TSOs. The goal of the TSO input is to secure operational stability and to maintain the frequency in such a way that the frequency quality requirements are met. In order to do so, the TSOs are responsible for making sufficient amount of balancing resources available considering the agreed minimum volumes. (ENTSO-E 2016) In addition, the parties have agreed that Statnett and Svenska Kraftnät, called as the balance operators hereafter, will lead the balancing, since approximately 75 % of the annual consumption of the Nordic synchronous system takes place in Norway and Sweden. During normal conditions, Fingrid and Energinet.dk will perform balancing operations only after contacting Svenska Kraftnät. (ENTSO-E 2017).

Along with the responsibilities, the Nordic system operation agreement defines boundaries for the frequency quality that are in compliance with the requirements set by the system operation guideline (SOGL). The synchronous system frequency is allowed to range between 49.90 and 50.10 Hz during normal operation and the balancing processes should aim to maintain 50 Hz frequency. The SOGL obliges the TSOs to keep the minutes outside of the normal frequency band below 15 000 minutes per year and the Nordic TSOs have agreed that the limit is 10 000 minutes per year, which fulfils the requirement set by the European regulation. The TSOs might want to deviate purposefully from the 50 Hz, for instance, during the morning hours when the consumption is ramping upwards. In such a situation, keeping the frequency higher than 50 Hz creates a better margin for balancing, because presumably the demand is going to increase further. (ENTSO-E 2016; EUR-lex. 2019a) Figure 3 below shows the development of the minutes outside the normal frequency band starting from 2002. It can be observed that the limit of 10 000 minutes per year has been violated several times during the recent years, which indicates that the system operation is challenged and it needs to be developed.

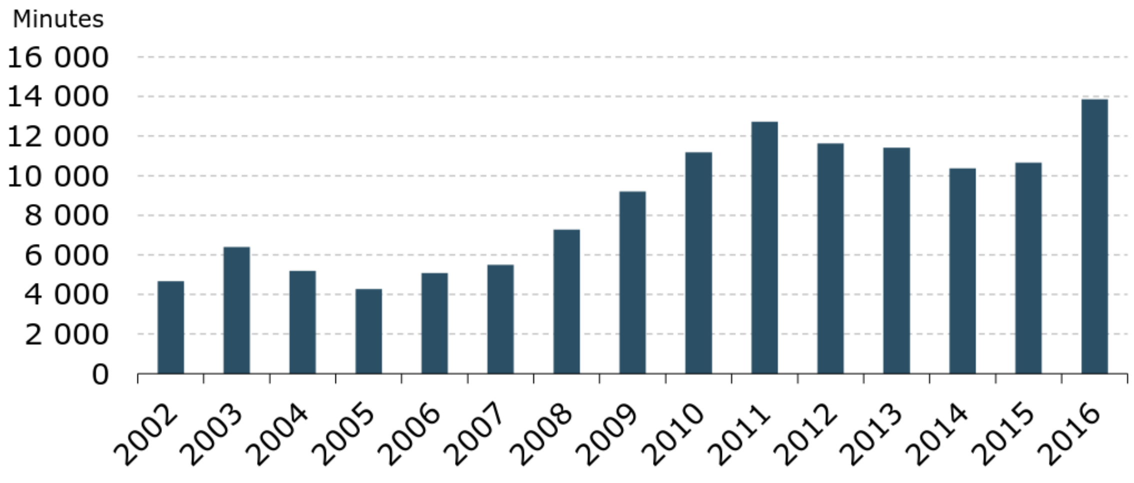


Figure 3: Minutes outside the normal frequency band in the Nordic synchronous system (Copenhagen Economics 2017).

2.2 Balancing products

The physical properties of the power systems define the requirements and preconditions for the frequency control structure and ancillary services. Figure 4 below illustrates some qualitative aspects that need to be considered when designing a basic control structure of a power system. Although the diagram is not all-encompassing, it can be interpreted that the nature and characteristics of power imbalances along with the network conditions determine what kind of control services and balancing products are needed.

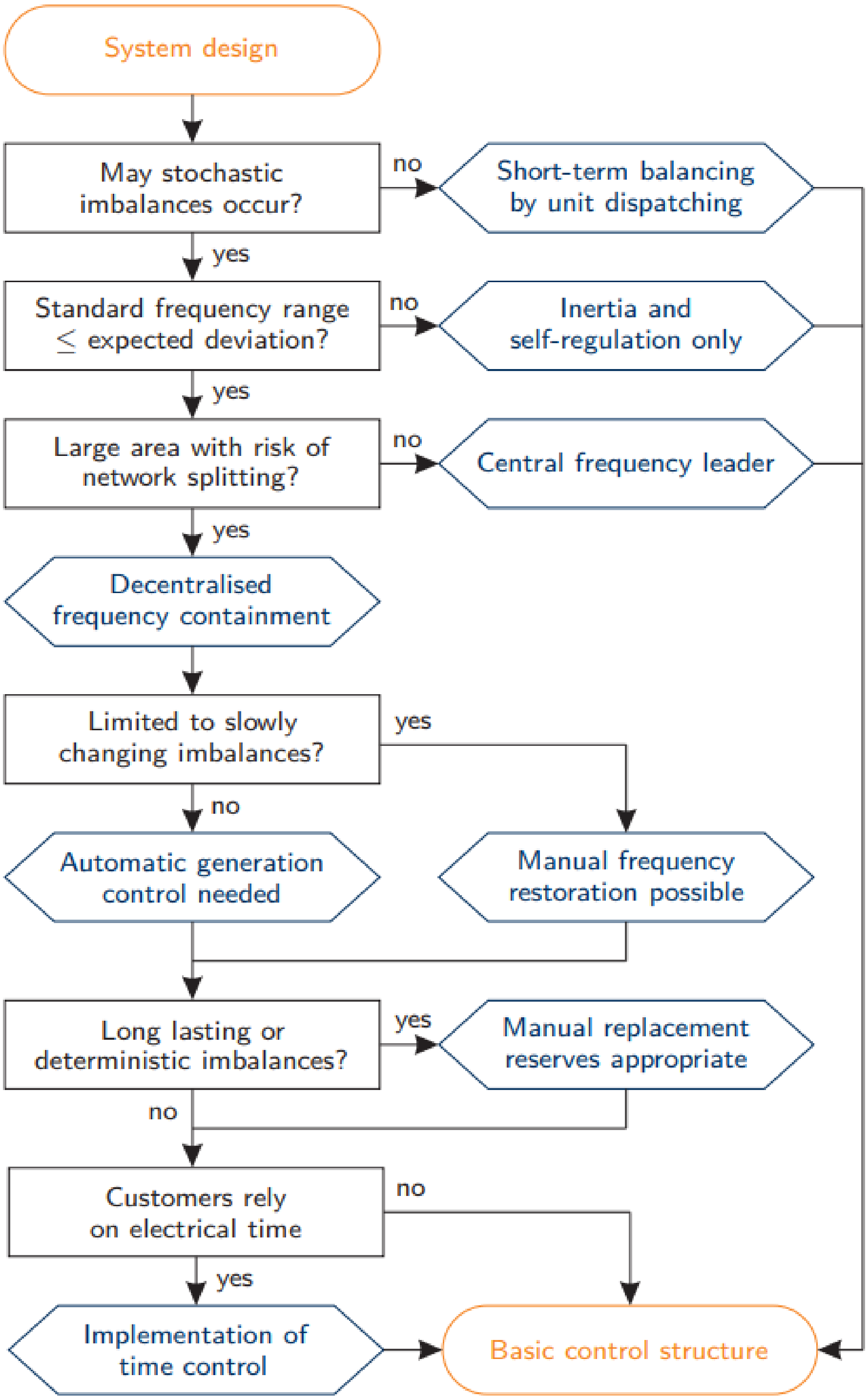


Figure 4: A high-level decision diagram concerning power system control structure (Scherer 2016).

Depending on the nature of the power system, multiple types of balancing power products are required in order to supply balancing power for the system appropriately. The balancing products have different physical properties, such as response time, activation frequency and way of activation (Hirth & Ziegenhagen 2015). The balancing product reserves are power plants or load resources that adjust their electricity production or consumption up or down according to the power system need. In the Nordic power system there are two types of reserves that are utilized in a different manner: Frequency containment reserves (FCR) are used for continuous frequency control and to stabilize the frequency whereas Frequency Restoration Reserves (FRR) are used to return the frequency back to its normal range and to release activated FCR. Replacement reserves (RR), on the other hand, are not used in the Nordic power system, but RR could be utilized to handle long lasting imbalances and to release activated FRR back into use. (Fingrid 2019a) FCR and FRR can be divided further into more specific products. Frequency containment reserves include products for normal operation (FCR-N) and for case of disturbances (FCR-D). FCR-N is utilized to balance the system frequency within the normal frequency range of 49.90 – 50.10 Hz and FCR-D is utilized for balancing in situations where the frequency falls below 49.90 Hz. They both activate automatically and are locally controlled according to the system frequency. Frequency restoration reserves include products that can be activated automatically (aFRR) or manually (mFRR). (ENTSO-E 2016) As shown in figure 5 below, it has been common to categorize the products into three control types according to their purpose of use: Primary control, secondary control and tertiary control (UCTE 2004). In the Nordics, both frequency containment reserve types are involved in the primary control, automatic FRR is secondary control and tertiary control include manual FRR.

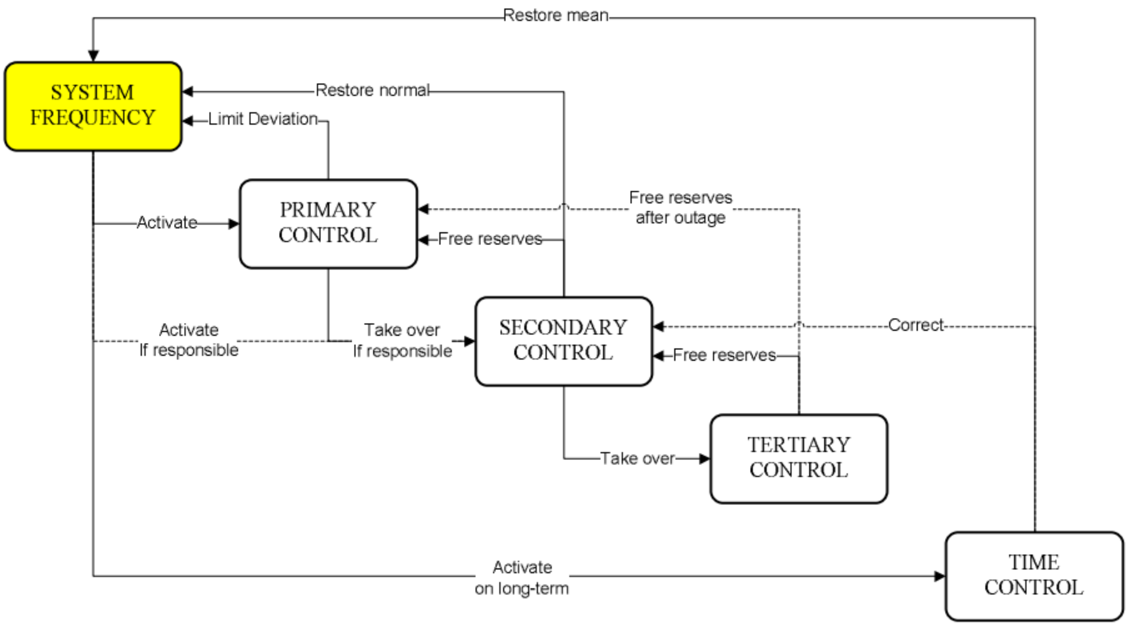


Figure 5: System frequency control types (UCTE 2004).

Fingrid procures all of these reserves by maintaining several marketplaces, where the balance service providers (BSP) submit bids regarding their reserve resources (Fingrid

2019b). The bids are divided into up balancing and down balancing bids. Up balancing is needed when the electricity supply is less than the demand, which can be managed by increasing production or decreasing consumption. On the other hand, down balancing is needed when the electricity supply is greater than the demand and then the solution is to decrease production or increase consumption.

2.2.1 Automatic frequency restoration reserves

aFRR is a balancing product that is remotely controlled according to the Nordic synchronous system frequency by a centralized controller. The frequency is metered continuously and its deviations determine the magnitude of the aFRR power change that is required to restore the frequency back to 50 Hz and to release activated FCR back into use. The Nordic TSOs have agreed on that the necessary power change calculations are performed in the supervisory control and data acquisition (SCADA) system of Statnett. After calculating the need of aFRR power change, Statnett sends activation signals to the relevant TSOs, which relay the signals further to the BSPs in their own control area. In Finland Fingrid transmits the activation signal every ten seconds. (Fingrid 2016a)

The sign of the signal defines the direction of the power change. Minus sign means that the reserve resource must perform down balancing and plus sign means the reserve resource must perform up balancing. The resource participating to the automatic frequency restoration reserves must be capable of reaching its full capacity within 120 seconds and the activation must start no later than 30 seconds after receiving the control signal. (Fingrid 2016a) Figure 6 below illustrates the activation time limits for the aFRR. The red line depicts the minimum activation speed of the resource.

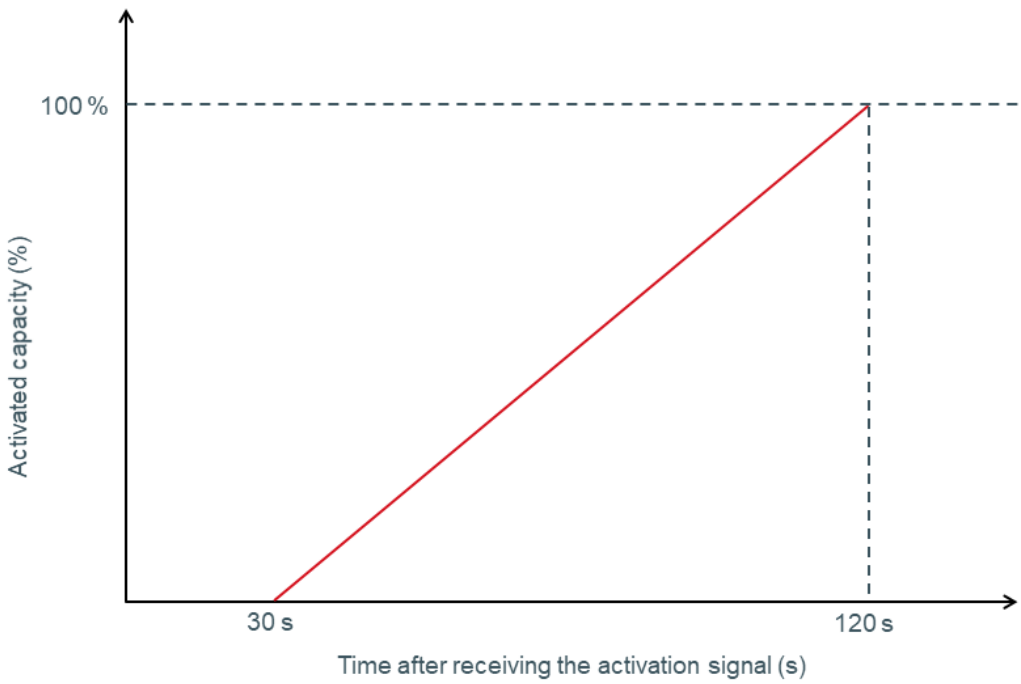


Figure 6: Time limits for aFRR resource activation in Finland.

Fingrid ensures automatic frequency restoration reserve availability by maintaining aFRR capacity markets and by ordering it from Svenska Kraftnät. aFRR capacity is procured only for certain morning and evening hours that are published well in advance. BSPs submit bids separately for up balancing and down balancing capacities and the size of an individual bid must be 5 MW at least. After the market closes, Fingrid sets the bids in ascending order of price and then the needed amount of up balancing and down balancing bids are contracted for balancing purposes. The relevant BSPs will receive capacity payment and energy compensation, which is determined based on the activated mFRR bids, since there is no energy activation market for the aFRR to determine the aFRR energy compensation. (Fingrid 2016b)

2.2.2 Manual frequency restoration reserves

Manual frequency restoration reserve is a balancing product that is utilized under normal and disturbance conditions in order to balance the frequency deviations and to handle possible power grid congestions. It is currently the main product for balancing and it releases both the activated FCR and aFRR back into use and simultaneously restores the frequency back to 50 Hz. mFRR is manual and slower product compared to aFRR in the frequency restoration process. The Nordic power system relies heavily on mFRR resources, since the aFRR volumes are limited. (ENTSO-E 2016)

Fingrid ensures the availability of mFRR via two marketplaces: capacity market and energy market. In the mFRR energy market, the BSPs submit bids concerning their adjustable resources that are still available after day-ahead and intraday trading. The bids include information, such as the capacity in megawatts and the energy price in euros per megawatt hour. Finnish BSPs submit the bids to a data system maintained by Fingrid and the bids must be submitted 45 minutes before the operating hour at the latest. After that, the Nordic TSOs send the bids on to a common Nordic balancing market list in which all the bids are set in order of price and necessary amount of bids are accepted taking into account cost optimization and congestion management. If a Finnish bid is chosen, Fingrid orders and activates the bid by either calling or transmitting an electronic message to the BSP. The minimum capacity of an electronically orderable bid is 5 MW and otherwise 10 MW. The reserve resources must be fully activated within 15 minutes after the order. (Fingrid 2019d)

The activated energy bids determine the balancing energy prices. In order to determine up balancing price the bids are set in ascending order of price and the most expensive activated bid determines the energy price for up balancing. According to this price, the BSP with accepted bid gets its energy payment from Fingrid. In order to determine down balancing price the bids are set in descending order of price and the cheapest activated bid determines the energy price for down balancing. According to this price, Fingrid charges the BSP with accepted bid for the energy. (Fingrid 2019c)

Along with the mFRR balancing energy market, Fingrid maintains mFRR capacity market. The balance service providers participating in the capacity market are obliged to submit bids to the above-mentioned mFRR energy market, if their capacity bids become accepted. The bids that are submitted under an obligation to the energy market supplement the bids that are submitted voluntarily. The mFRR capacity market bids include information about the capacity, which can vary between 5 and 50 MW, and the desired capacity payment. They are both fixed for a week period. The BSPs with accepted capacity bids will receive appropriate capacity payment. (Fingrid 2019e) The mFRR capacity market is maintained to ensure the availability of mFRR energy market bids in order to handle unforeseen power system faults and disturbances (Fingrid 2019c).

2.3 Balancing process

Power system balancing is a long process as a whole. Already years before real time operations market participants start to make financial product contracts. When moving closer to real time market participants enter the day-ahead and intraday markets to trade power with each other in order to achieve equilibrium between production and consumption. Simultaneously, the Nordic TSOs perform various tasks in order to secure efficient real time balancing process, for example, by ensuring balancing product availability via maintaining different marketplaces. TSOs need to execute the balancing process in such a way that the frequency quality requirements set are fulfilled within the synchronous system. The planning of the balancing process is dependent on the available information and Statnett together with Svenska Kraftnät are responsible for carrying out the actions of balancing under normal operating conditions. Figure 7 below illustrates parts of the information flow and some activities that are needed for the real time balancing.

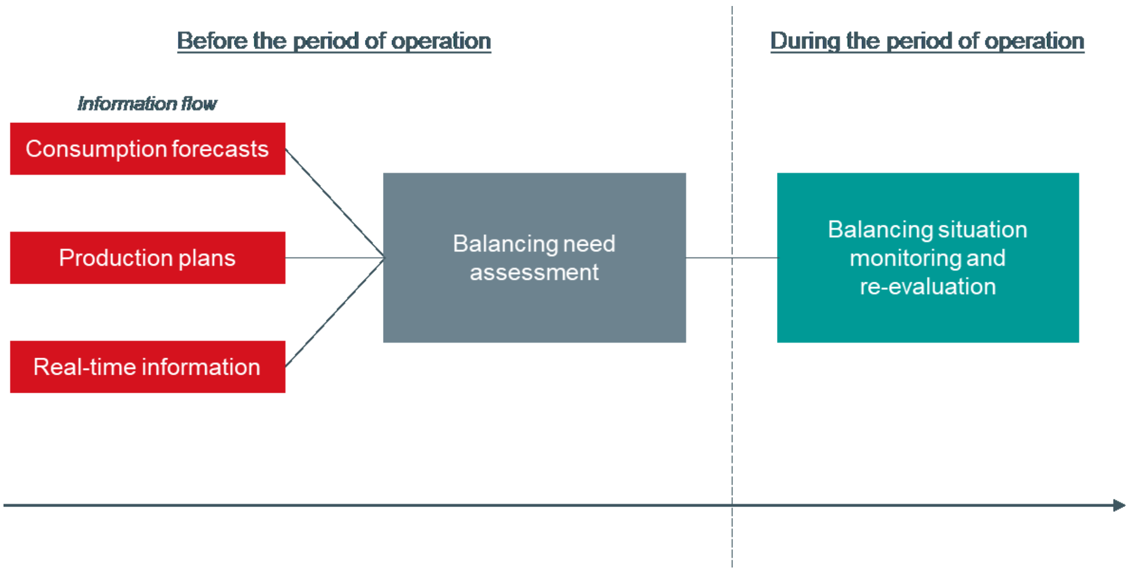


Figure 7: Illustration of the close to real time balancing process of the Nordic TSOs.

The information regarding the market actions starts to flow to the TSOs after the day-ahead market closure. By taking advantage of the available data, TSOs form an hour-by-hour overview for the next day, which gives an initial indication, for instance, if there will take place congestions in the power grid during the hours of the following day. Each TSO in the Nordic synchronous system makes their own overview assessment, but additionally, the balance operators make a coordinated version concerning the whole Nordic synchronous system. The assessment is based on various data including preliminary consumption forecasts produced by each TSO, preliminary production plans from BRPs, day-ahead exchange plans from Nord Pool taking into account AC- and DC-connections and preliminary balancing energy market bids. After the completion of the assessment, Fingrid can ask balance service providers to submit additional mFRR balancing energy bids, if there exist a threat of mFRR volume inadequacy. However, the request is not legally binding meaning that the balance service providers can freely decide whether to participate to the balancing energy marketplace or not even if they have available capacity. (ENTSO-E 2016)

When moving closer to real time, the next significant period from the balancing process point of view begins after the intraday market closure. All the information concerning the market actions and behavior of the market participants gets more accurate when approaching the operating hour. The balancing process planning goes further as the consumption prognoses, production plans and exchange plans are updated. In addition, the exact mFRR availability is known 45 minutes before the operating hour as the balancing energy market closes. All the above-mentioned data is gathered together in Nordic operational information system (NOIS), which is a common platform for the Nordic TSOs to provide relevant data. On the grounds of the compiled planning information and present operational situation, Statnett and Svenska Kraftnät evaluate the need for balancing, including balancing volume and direction, in the Nordic synchronous system during the following hour. The optimal utilization of balancing energy bids is agreed between the TSOs and the bids are used in order of price during normal conditions. The relevant TSOs will order the accepted bids by calling or by sending electronic message to the BSPs that eventually operate the resources. (ENTSO-E 2016)

During the operating hour, the balancing situation of the Nordic power system must be supervised non-stop by the balance operators. The need for balance readjustment must be continuously analyzed in a similar way to the evaluation process described above, but with shorter-term changes in mind. Therefore, the availability of planning data and real time measurements is important in order to utilize them as a basis for the re-evaluation. Occasionally the operators need to rely on rapid decision making concerning the power system balancing as there exists always a risk of unpredictable events, for instance power plant trips. The resulting solutions in such occasions are based on the available real time data and planned information. In addition, there may arise occasions in which the areas need to be balanced separately due to the limited availability of transmission capacity. The separation is jointly decided by the TSOs in real time. For example, Finland is one bidding area and Fingrid can balance it alone, if that is needed in order to solve the transmission system constraints. Congestions have always priority over the frequency in the Nordic synchronous system. (ENTSO-E 2016)

Due to the nature and composition of the Nordic power system, there may arise situations where actions that deviate from the normal balancing process are required, such as special regulation and hour shift planning. Special regulation is ordered from the balancing energy market by TSOs and instead of balance management, it is used for congestion management or to cover some unforeseen incidents taking place in the power system. The bids activated for the special regulation purpose are not necessarily used in order of price and they are not taken into account when determining imbalance power price, which is discussed more closely in the next chapter. In addition to the special regulation, the balance operators need to evaluate if there is a need to put forward or backward parts of planned production before the operating hour. Large production changes and HVDC exchange around the hour shift may result in frequency deviations that cannot be entirely tackled by following normal balancing processes. Thus, the balance operators may need to create a plan how to cope with the large changes by agreeing with the BRPs about the production rescheduling. (ENTSO-E 2016)

2.4 Imbalance settlement

Transmission system operators are responsible for ensuring real time balance between production and consumption, which is managed by activating different market-based balancing products. The need for such balancing come from the imbalances that are caused intentionally or unintentionally by different balance responsible parties (BRP) representing one or more market participants along with themselves. The BRPs are under an obligation of planning their production and consumption portfolios into balance on hourly basis and in addition, they need to submit hourly production plans to the TSOs. After the operating hour, all the realized and measured energy deliveries are compared to the initial energy plans and the BRPs are penalized with an imbalance price, if deviations exist. This is called as the imbalance settlement process, which gives the BRPs an incentive to behave in a certain manner. Without financial consequences there would not exist any BRP interests toward balancing. (van der Veen & Hakvoort 2009)

The imbalance settlement process and services are brought to the market participants in Finland, Norway and Sweden by eSett, which is jointly owned by the TSOs of the countries in question. The role of eSett is to act as the Nordic imbalance settlement responsible, which performs the imbalance settlement process including various operations and tasks, such as the data collection, validation and management in addition to the settlement calculations and charging the BRPs in accordance with the caused deviations over the imbalance settlement periods. The ultimate settlement responsibility belongs to the TSOs that are open suppliers for the BRPs and carry out actions in order to rebalance the system.

After the imbalances of the BRPs are settled and the balancing costs are allocated amongst the relevant BRPs, the imbalance settlement shifts downwards along the open supplier chain to the level that connects the balance responsible parties with electricity retailers. As the BRPs may take care of the balancing obligation on behalf of other market participants, they are most likely willing to get compensation for the imbalances that are caused by their clients. Thus, the BRPs may allocate the balancing costs further to the relevant electricity retailers depending on the agreement they have made. The whole calculation process is based on energy metering data that is received from distribution system operators (DSOs), which operate the energy measurement processes within metering grid areas (MGA). (eSett 2019) Figure 8 below illustrates the linkages between different parties related to the imbalance settlement.

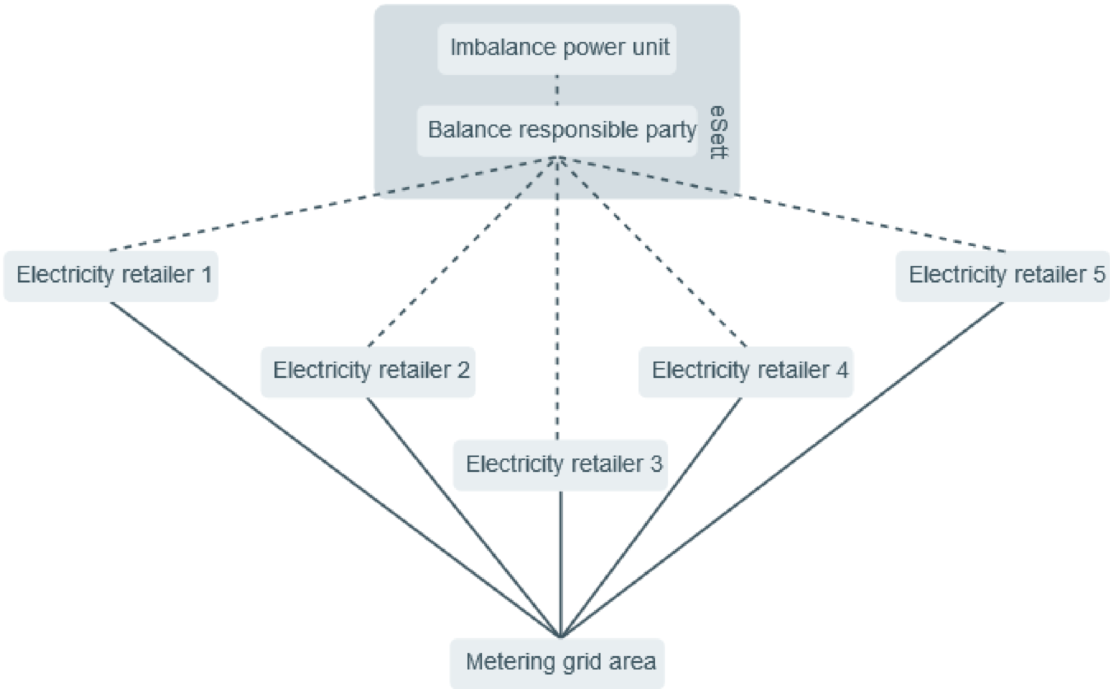


Figure 8: Interactions between different stakeholders regarding the imbalance settlement process in the Nordics (Fingrid 2019f).

The settlement model that is utilized to sort out the imbalances of the BRPs was introduced in 2009 and is based on two different calculations: The imbalance volumes of production and consumption are calculated separately as presented in figure 9 below. The production imbalance volume is calculated by subtracting the planned production from the actual measured production. In addition, production imbalance adjustment is required if a production resource object included in the portfolio of the BRP has participated in the balancing energy market. The consumption imbalance is calculated as the deviation between consumption, planned production, trades, consumption imbalance adjustment and metering grid area (MGA) imbalance, which includes the grid losses taking place in the distribution network. (eSett 2019)

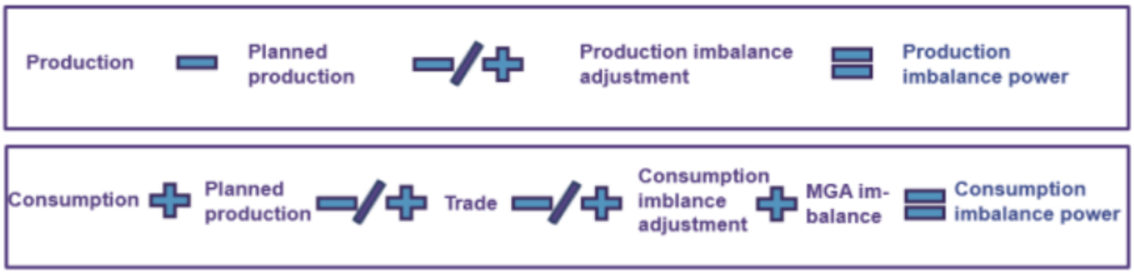


Figure 9: Equations to calculate production and consumption imbalance volumes (eSett 2019).

The two imbalances are priced differently: Dual pricing is applied to the production imbalance and single pricing is applied to the consumption imbalance. The first means that positive and negative production imbalances have different prices and the second means that the same price is applied to both positive and negative consumption imbalances. As the pricing models for the production and consumption imbalances differ, the financial incentives encourage the BRPs to manage the two imbalances differently. The dual price model for the production imbalance works as the follows: If a BRP has a negative production imbalance over an hour in which the main balancing direction is up, the BRP is obliged to purchase energy from eSett with an up balancing price in order to fulfil the energy deficit that took place over the operating hour. If the BRP has a positive production imbalance over an hour in which the main balancing direction is up, the BRP is obliged to sell the excess energy with day-ahead price in order to trade away the surplus that occurred over the operating hour. During an hour in which the main balancing direction is down, a BRP with a negative production imbalance is obliged to purchase missing energy with day-ahead price and if the production imbalance is positive, the BRP is obliged to sell the produced excess energy with down balancing price. (eSett 2019)

This mechanism creates an incentive for the BRPs not to cause production imbalances against the main balancing direction, as the up balancing price is typically higher and the down balancing price is typically lower than the day-ahead market price. Thus, during an up balancing hour, a negative production imbalance will result in additional costs, as the energy would have been cheaper in the day-ahead market. On the other hand, a positive production imbalance will not provide any additional profit for the BRP, because the price is the same as in the day-ahead market. During a down balancing hour, a negative production imbalance will not bring any additional profit, since the price is the same as in the day-ahead market. On the other hand, a positive production imbalance will provide lower profit for the energy as the BRP needs to sell it for the down balancing price, which yields less income than the day-ahead market price.

The single price model for the consumption imbalance incentivize the BRPs to behave in such a manner that the consumption imbalances they bring on support the power system. This can be explained by the pricing as the same price is applied to both positive and negative consumption imbalances. Thus, if the imbalances of the BRPs are to the main balancing direction, the BRPs can make more profit by creating intentional imbalances than trading on the day-ahead market. (eSett 2019) Table 1 below elaborates how the different balancing prices are applied. It is important to understand, that if the BRPs are willing to cause intentional imbalances within the period of operation, i.e. exercise self-balancing, it means that the BRPs must have proper knowledge about the balancing situation of the power system in real time in order to cause imbalances in the right balancing direction.

Table 1: Pricing of consumption and production imbalances.

	Hours in which the main balancing direction is up	Hours in which the main balancing direction is down	Hours with no balancing direction
Dual price model for production imbalances			
Negative production imbalance	Up balancing price	Day-ahead market price	Day-ahead market price
Positive production imbalance	Day-ahead market price	Down balancing price	Day-ahead market price
Single price model for production imbalances			
Negative consumption imbalance	Up balancing price	Down balancing price	Day-ahead market price
Positive production imbalance	Up balancing price	Down balancing price	Day-ahead market price

The whole imbalance settlement process including the allocation of imbalance costs to the relevant BRPs works as a basis for power system balancing. The incentive mechanism that results from the imbalance settlement model directs the balance responsible parties to behave according to a certain manner. The behavior of the BRPs and the resulting imbalances form the system imbalance, which affects the power system frequency and which needs to be taken care of by the responsible transmission system operators. The TSOs perform actions and activate market-based balancing resource bids in order to mitigate the power system imbalance. The activated balancing energy bids determine the balancing energy prices, which work as a foundation for the imbalance pricing, which is clarified in the table above. For the present, activated mFRR energy bids determine the balancing energy prices, although automatic frequency reserves and frequency containments reserves also contribute to the system balancing (ENTSO-E 2016). Imbalance settlement and pricing affect how the BRPs are compensated or charged depending on their imbalances and the balancing state of the power system. This whole chain of consequences can be referred to as the feedback loop, which is demonstrated in figure 10 below. It shows how the different events and actions related to balancing are linked together and how the feedback loop should ultimately refine the market behavior of the BRPs. However, if the financial consequences for the BRPs are not sufficient, the loop lacks control effect (van der Veen & Hakvoort 2009).

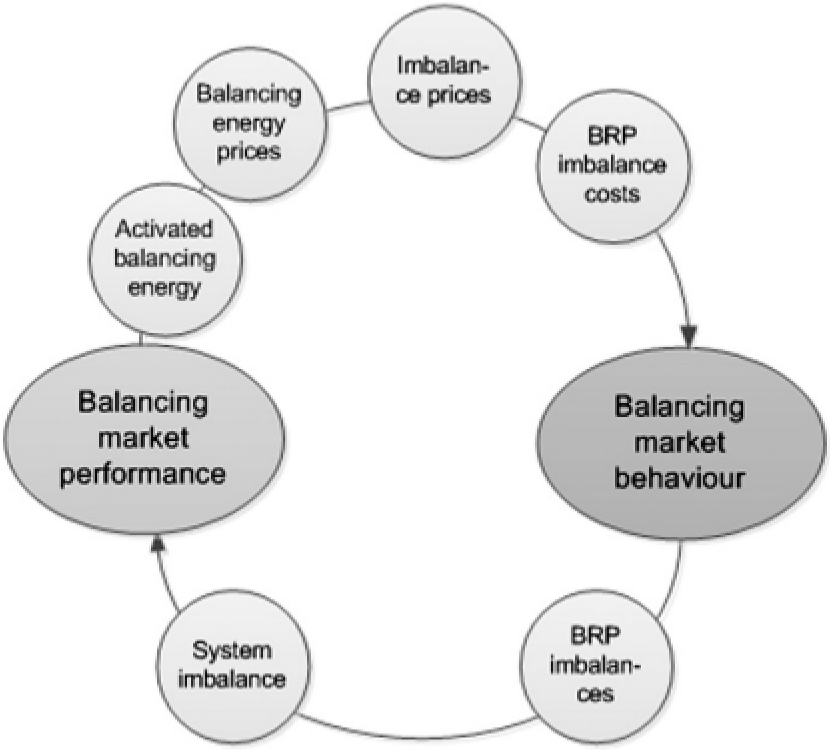


Figure 10: The feedback loop, which refines the BRP behaviour (van der Veen et al. 2012).

3 Future of the Nordic power system balancing

In 2018 the Nordic TSOs concluded a cooperation agreement, which defines the roles and responsibilities of the TSOs concerning future Nordic balancing. The agreement obligates the TSO to follow a mutual roadmap regarding implementation and development of the new balancing model and common balancing markets. It also outlines the tasks related to the new balancing structure. (Statnett 2019) In addition, system operation guideline (SOGL) and electricity balancing guideline (EBGL), which are both European regulation, have set new requirements for the TSOs that need to be implemented. This chapter will discuss key elements of the Nordic balancing development more closely and introduce area control error based balancing model, which is one of the cornerstones of the future Nordic power system balancing. The European balancing market platforms MARI and PICASSO are considered as well, since they will contribute to the development and integration of balancing on European level.

3.1 Key elements of the Nordic balancing development

There exist plenty of driving forces behind the development of the Nordic power system balancing. One of the main goals of the Nordic balancing cooperation is to secure and enhance operational security of the system in the short and long term. This is ensured by means of improving the efficiency of system operation and clarifying the responsibilities and freedoms related to the tasks and functions of the Nordic transmission system operators: Each TSO shall be more in charge of the imbalances that arise out of own control area. Another significant objective is to support the security of supply and socio-economic welfare now and in the future. This is guaranteed by the utilization of market based solutions that create well-functioning and transparent markets. Third driving force to be considered is the fact that the Nordic power system balancing should meet the requirements of European regulation and legislative instruments. All of these aspects together will enable the transition towards clean and intermittent power system. (Affärverket Svenska kraftnät et al. 2018) This chapter will introduce the key elements that form the core of the Nordic power system balancing development and that help the Nordic TSOs to reach the discussed goals.

3.1.1 LFC structure and ACE

Currently the responsibility for maintaining the frequency and time deviation within set limits in the Nordic synchronous system is an operational duty allocated to Svenska Kraftnät and Stattnet, which is agreed in the Nordic system operation agreement (SOA). This will be changed due to the new cooperation agreement and the implementation of area control error (ACE), which will increase the operational responsibility of each Nordic TSO for maintaining balance in own control area. In the future, the Nordic synchronous system is comprised of one load frequency control (LFC) block, which consists of bidding zones that are formed considering the major bottlenecks in the power grid. Each bidding zone will be an LFC area. (Affärverket Svenska kraftnät et al. 2018) The obligation for the determination of the LFC block and areas comes from the SOGL article 141(2), which states that all the TSOs of a synchronous area shall together develop a proposal concerning the LFC structure (EUR-lex 2019a). Figure 11 below shows how the Nordic system will be divided into LFC areas. It can be observed that Finland corresponds to one LFC area.

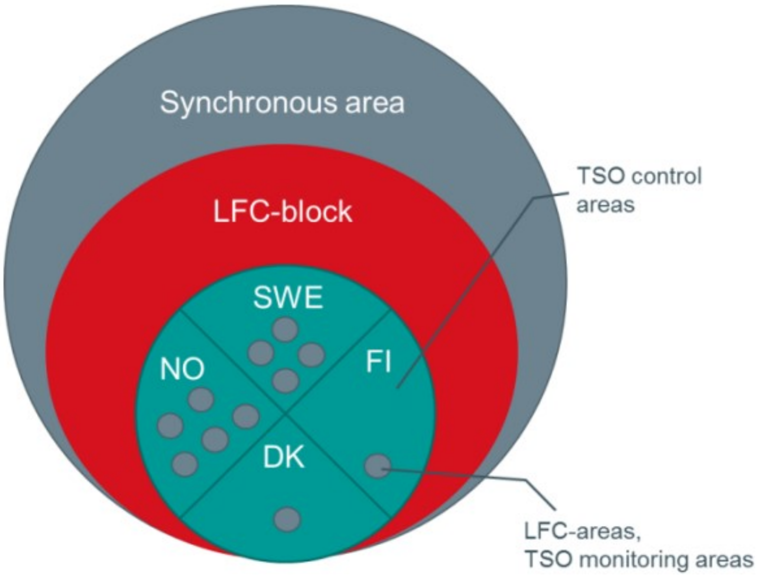


Figure 11: LFC structure in Nordic synchronous area (ENTSO-E 2018a).

The cooperation agreement and ACE based balancing model will entail changes to the tasks and responsibilities of the Nordic TSOs. ACE is a calculated measure reflecting the instantaneous power imbalance in an LFC area. In the future, each TSO is responsible for calculating ACE and ACE open loop per LFC area, which should be handled no later than 10 seconds after real time. For each LFC area, the relevant TSO should also generate an LFC controller, which calculates automatic frequency restoration reserve demand for the LFC area based on ACE calculations and already activated aFRR. In other words, the LFC controller directs the utilization and activation of automatic frequency restoration reserve. Along with these tasks, each TSO should calculate LFC area imbalance prognosis for the upcoming period of operation. Additionally, each TSO should be capable of calculating and making request for manual frequency restoration reserve activations and the imbalance prognosis should work partly as a basis for the assessment of mFRR demand. (Affärverket Svenska kraftnät et al. 2018)

These tasks and responsibilities imply that under normal operational conditions, the automatic frequency restoration reserve is utilized for reactive balancing and the manual frequency restoration reserve is for proactive balancing, which means that it is utilized to take care of the forecasted imbalances and to release expected aFRR activation. However, the establishment of LFC controller and imbalance prognosis model for each LFC area is a duty that is allocated to each relevant TSO, which means that the TSOs have some freedom related to the design of those functions. Thus, each TSO can influence on how the balancing products are utilized inside own LFC areas, which highlights the need for discussion concerning balancing philosophy.

3.1.2 Advances in frequency restoration reserve markets

The new cooperation agreement brings also tasks and responsibilities for the Nordic TSOs related to the development of manual and automatic frequency restoration reserve markets. Each TSO is responsible for establishing a method to gather aFRR and mFRR energy activation bids from balance service providers. The TSOs should also be capable of recognizing and marking bids that cannot be activated because of internal bottlenecks inside the LFC areas. After these procedures, the TSOs should have an ability to make the bids available for the Nordic activation optimization functions (AOF), which are developed and operated by the common service providers that are Svenska Kraftnät and Statnett in the Nordics. Both manual and automatic FRR types will have an own specific AOF, but they will work according to the same basic logic: Both of the functions optimize the activation of reserve resources over all of the Nordic LFC areas taking into account demand, netting possibilities, available transfer capacity and bid prices. In addition, the AOF for mFRR should respect the design of MARI, which is the new and upcoming European manual frequency restoration reserve platform, and the AOF for aFRR should respect the design of PICASSO, which is the new and upcoming European automatic frequency restoration reserve platform. Along with sustaining proper marketplaces, each individual TSO needs to have a way of sending electronic activation signals to the BSPs operating the aFRR and mFRR resources that are chosen to be activated. In addition, marginal pricing should be implemented for aFRR and both reserve types should be priced on 15 minutes basis. (Affärverket Svenska kraftnät et al. 2018) Currently, there is balancing energy market only for the manual frequency restoration reserve, but the abovementioned matters signify that there will also be an energy activation market for automatic frequency restoration reserve in the future. In addition, 15 minutes pricing will be applied to both reserve types instead of 60 minutes pricing, which is currently implemented for the mFRR energy market.

Along with the development of manual and automatic frequency restoration reserve energy markets, the capacity markets for both reserve types will undergo major changes. In the cooperation agreement it is included that the common service providers Svenska Kraftnät and Statnett are responsible for the development and operation of a Nordic capacity market for mFRR and aFRR. The system they will establish should be capable of collecting bids from all the balance service providers in the Nordics and monitoring capacity reservation algorithm. Each individual TSO must calculate the volume of capacity needed to be procured in compliance with the set dimensioning principles and ensure that the infrastructure of communications towards the BSPs is sufficient. All the Nordic TSOs are allowed to join the common capacity market for aFRR and mFRR, but the participation is not required. (Affärverket Svenska kraftnät et al. 2018) Currently, the mFRR and aFRR capacities are procured mainly from national markets with a few exceptions, but the changes presented above will enable shifting the procurement from national to Nordic level.

3.1.3 15 minutes imbalance settlement period

An imbalance settlement period (ISP) is a time unit for which the imbalances of the BRPs are calculated. It directs the behavior of the BRPs, since they will be penalized for their imbalances that they cause over the ISPs. The article 53 of the electricity balancing guideline (EBGL), which concerns imbalance settlement period, states that all the TSOs shall apply 15 minutes ISP in all control areas. In addition, it sets an obligation to the TSOs about the market time unit (MTU), which shall be equivalent to the boundaries of the imbalance settlement period. (EUR-Lex 2019b) Currently the imbalance settlement period of 60 minutes is in use in the Nordics. Similarly, the market time unit is 60 minutes. Thus, the implementation of the requirements coming from the EBGL will shorten these time units to a quarter, which will have a great influence on the market behavior and power system balancing.

3.1.4 Single price and single position imbalance model

Imbalance pricing and calculation model is one of the key market design elements having an influence on the behavior of the balance responsible parties. The imbalance settlement process has many objectives. For instance, it should provide sufficient price signals that reflect the balancing situation of the power system. In addition, the price signals should reflect the real time value of energy. Briefly, the imbalance settlement should ensure that the incentives are adequate so that the BRPs are willing to be in balance or to support the system with imbalance mitigation. In order to prevent an unlevel playing field for the BRPs across Europe and between different countries, the EBGL obliges the TSOs to further specify and harmonize imbalance settlement in accordance with Article 52(2). The article in question concerns the calculation of imbalances, its main components and the use of imbalance price mechanism. (EUR-Lex 2019b)

The all TSOs' proposal to further specify and harmonize imbalance settlement in accordance with the abovementioned EBGL article 52(2) states that the European TSOs shall apply a single imbalance position for self-dispatching models, which concerns the Nordic TSOs. This is due to the fact that single position is more simple compared to the model of two positions. In addition, majority of the European TSOs utilize it already and from the BRP point of view, it will ease the control of imbalances. It is also noteworthy that the imbalance settlement based on single position model do not involve generation schedules. (ENTSO-E 2018b) This implies that the Nordic TSOs, which calculate two separate imbalances need to change the basis of their imbalance calculation by implementing the model of single imbalance, which is also referred to as single position. In addition, this means that the production plans will no longer be a part of the upcoming imbalance settlement model.

Along with the shift to single imbalance position, the all TSO proposal takes a stand on imbalance pricing mechanism. The EBGL obliges, that all the TSOs must put single imbalance pricing into operation. However, the EBGL also lets the TSOs to define conditions and methodology for applying dual imbalance pricing. According to the explanatory document of the all TSO proposal, an example of such a condition is a situation in which the system operator identifies an operational necessity to diminish the influence of overpowering self-balancing of the BRPs, which may threaten the operational security. In such situations, the dual imbalance pricing may restrict the self-balancing behavior and reduce the risk of negative impacts. (ENTSO-E 2018b) The shift towards single pricing will mean a significant change to the Nordic TSOs, which apply dual pricing for the production and single pricing for the consumption imbalance currently. In the future, production and consumption are included in a single imbalance position and the single price mechanism is applied to the occurring imbalances.

All of these key elements entail a multitude of changes and modification not only for the Nordic TSOs but also for all the Nordic stakeholders and market participants. Thus, the roadmap regarding the implementation of these elements is under a consultation process, which ensures that the stakeholders' point of view related to the implementation schedule is also recognized (ENTSO-E 2019). The roadmap categorizes the changes into two generations: The first generation includes the Nordic aFRR and mFRR capacity markets, single price model, 15 minutes ISP and mFRR activation based on ACE. The second generation contains aFRR energy activation market and full ACE based balancing model implementation. (Svenska Kraftnät et al. 2019)

The roadmap that is compiled by the Nordic TSOs includes a draft version of a timetable, which considers the first generation changes. The Nordic capacity market for automatic frequency restoration reserve has a go-live date in March 2020. The Nordic capacity market for manual frequency restoration reserve has a go-live date in the third quarter of the year 2021. The implementation of 15 minutes imbalance settlement period will take place in the fourth quarter of the year 2022, which is an initial date that may change after the consultation process closes. Simultaneously with the introduction of 15 minutes ISP the market time unit of the intraday market will shift from 60 minutes to 15 minutes. The Nordic TSOs will start the activation of mFRR based on ACE in year 2023, which highlights the need for balancing process automation. The go-live date of single imbalance price and position will be determined after the consultation process, since the TSOs need time to weigh all the possible alternatives. Some of the activities require regulatory processes and all of the changes are going to take a lot of modifications related to the operations and ICT-systems and hence, there may exist a demand for revising the draft timetable. The roadmap for the second generation changes will be clarified and published later on. (Svenska Kraftnät et al. 2019)

3.2 Fundamentals of area control error (ACE)

In the cooperation agreement of the Nordic TSOs, area control error (ACE) is defined as a measure, which reflects the instantaneous power imbalance in an LFC area of the Nordic synchronous power system (Affärverket Svenska kraftnät et al. 2018). On the other hand, according to EUR-Lex (2018a) the system operation guideline (SOGL) defines ACE as follows: "*Area control error* or *ACE* means the sum of the power control error ('ΔP'), that is the real time difference between the measured actual real time power interchange value ('P') and the control program ('P0') of a specific LFC area or LFC block and the frequency control error ('K*Δf'), that is the product of the K-factor and the frequency deviation of that specific LFC area or LFC block, where the area control error equals ΔP+K*Δf." In other words, ΔP is the difference between the actual power flow and the scheduled power flow on all borders of an LFC area, whereas Δf is the difference between the actual frequency and the scheduled frequency. The K-factor is a bias factor, which is individually assessed for each LFC area. Ideally, a control area should only take care of the imbalances in that area and not counteract its primary reserve contribution, the self-balancing of load or the auto-control of generation, which is why the bias factor K is needed. (Kundur 1994; Polajžer et al. 2018) ACE open loop is defined as the value of the ACE without any control processes (Nobel 2016). Basically, the area control error reflects the required power change in an LFC area. It is noteworthy, that frequency restoration control error (FRCE) is the control error for a frequency restoration process purposes and sometimes it is used as a substitute for the term ACE (Emissions-EUTS.com 2019b). Equation 2 below elaborates the calculation of area control error.

$$ACE = \sum (P^{phys} - P^{set}) - K(f^{phys} - f^{set}) \tag{2}$$

Where,

$\mathbf{P^{phys}}$ = Actual power flow on an LFC area border

$\mathbf{P^{set}}$ = Scheduled power flow on an LFC area border

K = Bias factor of an LFC area

$\mathbf{f^{phys}}$ = Actual LFC area frequency

$\mathbf{f^{set}}$ = Scheduled LFC area frequency

The most common way to handle power system secondary control is by implementing automatic generation control (AGC). In order to control automatically the power and frequency of power systems, the TSOs require proportional integral (PI) controllers. These controllers can work together with supervisory control and data acquisition (SCADA) systems that are utilized by the TSOs to collect data related to the power system. The AGC controllers, which are called LFC controllers hereafter, send activation requests to the secondary control reserve resources in a way that is most economical and feasible to take care of the power system imbalances. (NERC 2011; Panwar & Chahar 2016) Equation 3 below shows an example formula, which can be utilized by an LFC controller to calculate the control signals (P^{AGC}), which are sent to the reserve units that deliver the relevant amount of power. The ACE calculation provides the control error for the LFC controller and it works as a basis for calculating the control signals. The proportional term C typically varies between 0 and 0.5, and the integral term T varies between 50s and 200s. (Scherer 2016) With digital systems the experience has shown that the calculation of area control error and control signals once every 2 to 4 seconds leads to good performance (Kundur 1994).

$$P^{AGC} = -\left(C * ACE + \frac{1}{T}\int ACE\ dt\right) \tag{3}$$

Where,

C = Proportional term

ACE = Area control error

T = Integral term

Figure 12 below represents a basic ACE-based control structure of a system that takes advantage of four different control types. The illustrated LFC area in question uses frequency containment process as the primary control of power. The frequency containment reserves (FCR) are adjusted by controllers that locally follow the power system frequency. The secondary control, which can be called as automatic generation control (AGC), rely on frequency restoration process and more specifically, on automatic FRR. The PI controller, which can be referred to as LFC controller, uses area control error as a source information to calculate the control signals (P^{AGC}) that are sent to the relevant automatic frequency restoration reserve units. The tertiary control is managed by carrying out manual actions. From a control point of view, the manual FRR and replacement reserves (RR) are identical, but they differ from each other in terms of activation time (Scherer 2016). Time control is also carried out by manual actions that can include the activation of mFRR or RR. All of these processes have an influence on the ACE calculation. The primary, secondary and tertiary control change the value of actual power flow, which is compared with the scheduled power flow. As the equation 2 and 3 above show, this alteration will change the area control error and thus, affect the operation of the LFC controller, which in turn has an impact on the utilization of automatic frequency restoration reserves. In addition, the time control affects the frequency deviation, which will change the value of the area control error.

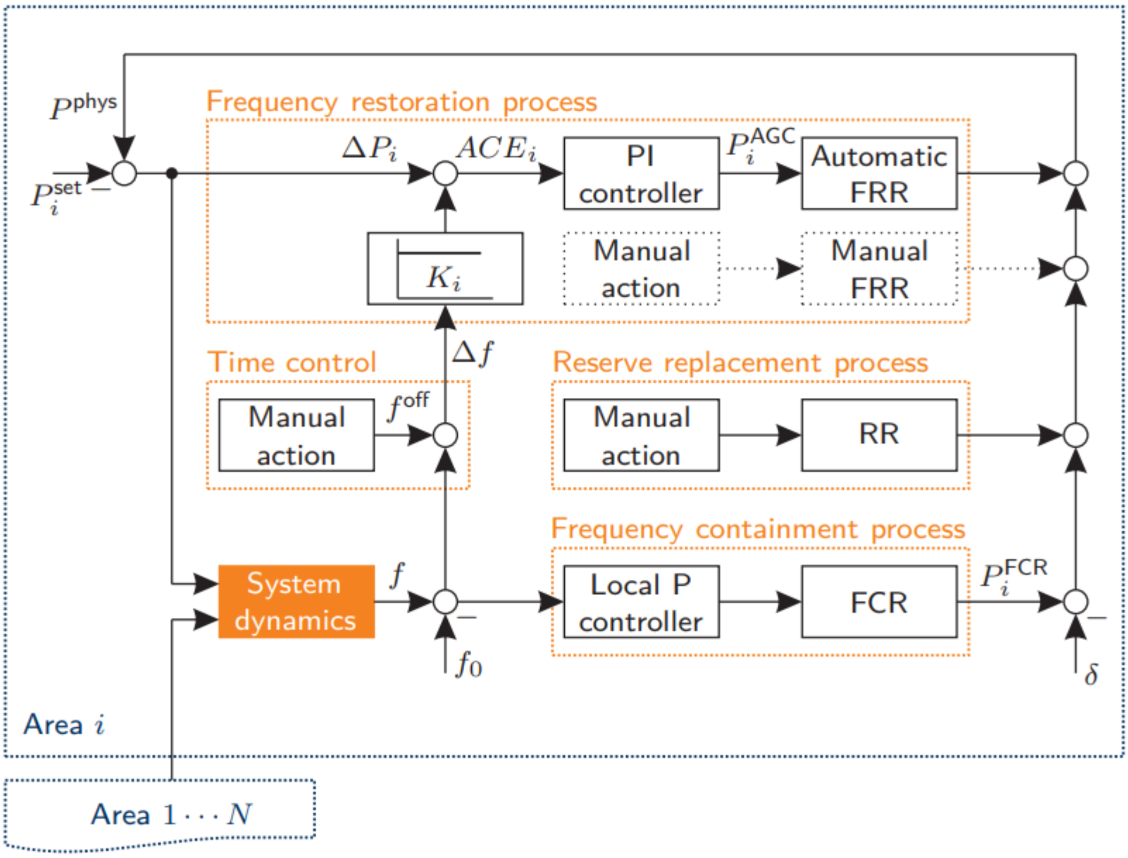


Figure 12: An elementary diagram depicting TSO control structure in a system that utilizes four-level frequency control and is based on calculating area control error (Scherer 2016).

TSOs that exercise ACE-based balancing try to return area control error close to zero (Liu et al. 2015). Zero ACE means that there are no instantaneous power imbalances in the control area and thus, the power system frequency is as desired. However, due to the nature of power systems, stochastic imbalances occur constantly, which brings on challenges concerning the pursuit of zero area control error. Therefore, it may be reasonable to set control performance criteria for the ACE-based balancing. According to Kundur (1994) the North American Reliability Council (NERC) has specified guidelines for the North American utilities. For normal conditions the following criteria apply: The area control error must equal to zero at least once every 10 minutes. In addition, the average ACE of each 10-minute period must follow specific limits that are determined taking into account the relevant control area characteristics. There are separate control performance criteria for the cases of disturbances: The ACE must return to zero after 10 minutes from the start of a disturbance at the latest. Additionally, the restoration process of the area control error must start not later than 1 minute from the start of a disturbance. Disturbance is a situation when the ACE is more than three times greater than the specific limits set for the normal operational conditions and it may be caused by a power plant trip or sudden increment in consumption. In such situations, the utilization of manual actions and products is a necessity.

3.3 Imbalance prognosis model

The Nordic cooperation agreement obliges the TSOs to develop a prognosis model for each LFC area. The model should calculate power imbalance, which can be referred to as forecast of area control error, for the upcoming operating period. The resulting number should work as a source information for the determination of the manual frequency restoration reserve demand. (Affärverket Svenska kraftnät et al. 2018) In order to satisfy this obligation, Fingrid needs to create only one imbalance prognosis model, since Finland consists of only one LFC area. The inputs that are utilized by the prognosis model have an influence on the accuracy of the result and thus, from the balancing philosophy perspective, it is meaningful to consider more closely the components involved in the prognosis calculation as the proactive design is highly dependent on forecasting.

A high-level scheme of the prognosis model illustrated in figure 13 below is based on production forecast, consumption forecast and estimated power flows across the borders. The production forecast is based on the production plans of balance responsible parties that are submitted to Fingrid well before the upcoming operating period. The consumption forecast is generated in Fingrid's own systems and it is based on various data, for instance former consumption data and weather conditions. Along with these two elements, there is several cross border power flow estimations that need to be considered. The estimated power flow over Russia-Finland border is based on trades including both bilateral trades and Finland-Russia exchange (FRE) trades. The estimated power flow across Estonia-Finland border is also based on trades. The power flow between Sweden and Finland is based on trades taking into account two Swedish bidding zones: SE1 and SE3. When the estimated power flows and the consumption forecast are subtracted from the production forecast, the result is the predicted power surplus or deficit of Finland's LFC area for the upcoming period of operation. Along with the discussed elements, the model may adopt correction factors that refine the accuracy of the prognosis. (Nevalainen 2019) For example, if the production forecast is 6400 MW, the consumption forecast is 8700 MW and the estimated overall power flow across the borders is 2580 MW of import, the result is surplus of 280 MW, which needs to be balanced away. However, the result is just an approximation, which is based on the assumption that the utilized source information is accurate and reliable. The upcoming market changes will have a significant impact on the production plans, which will directly affect the discussed imbalance prognosis model. Thus, it is reasonable to examine the usability of production plans in a more elaborate manner, which is done in chapter 4.4.

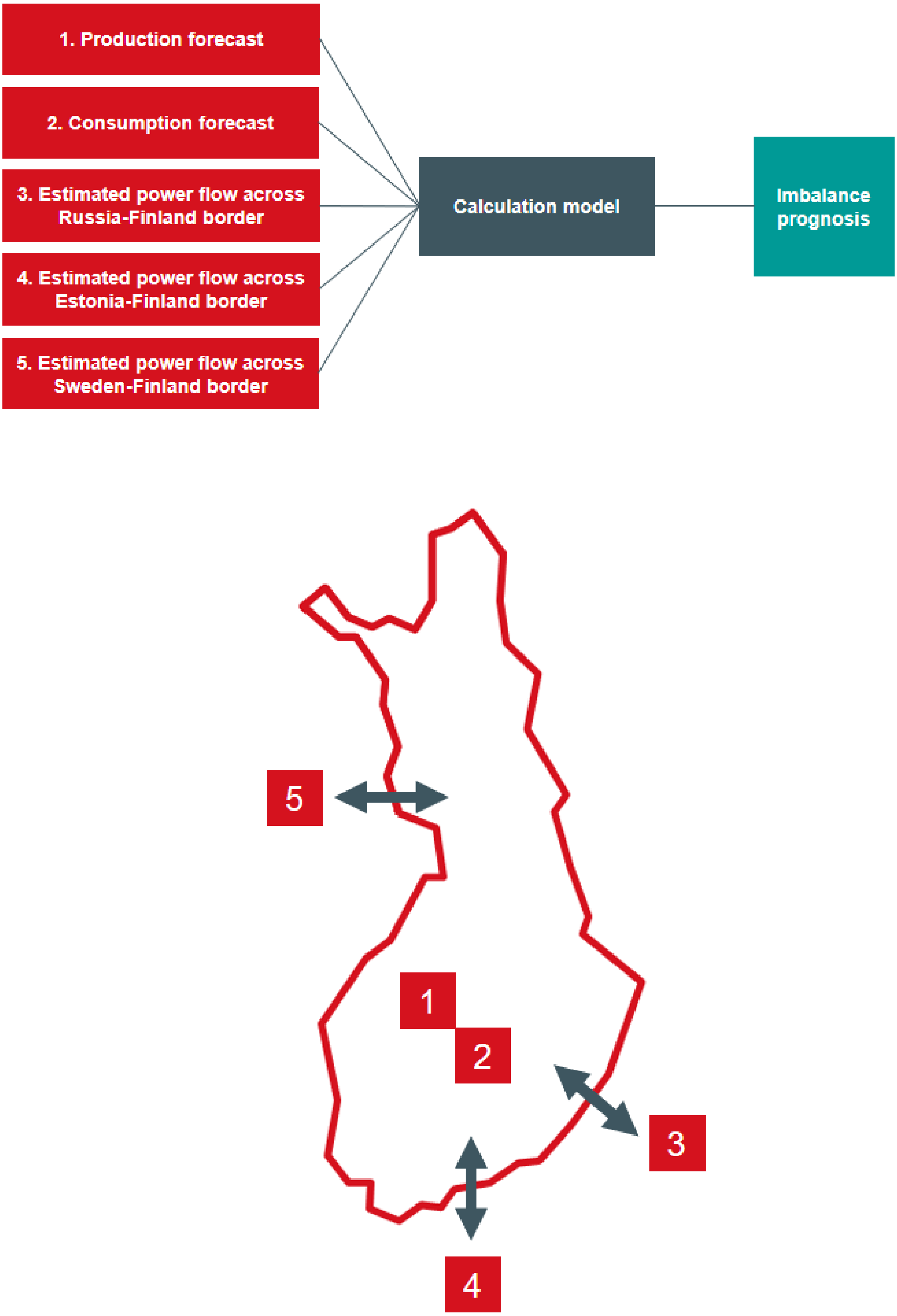


Figure 13: A high-level draft of Finland's imbalance prognosis model.

3.4 From Nordic to European balancing markets

One of the major goals of the electricity balancing guideline is to integrate and harmonize balancing markets and processes throughout Europe in a way that provides the European market participants with a level playing field. In order to satisfy this objective, some the technical specifications and requirements along with the market rules regarding balancing and balancing products need to be unified at European level. (ENTSO-E 2018c) The EBGL have set legal obligations for the TSOs concerning the integration and harmonization of the manual and automatic frequency restoration reserves. The EBGL articles 20 and 21 state that all the TSOs shall develop a proposal for the implementation framework for a European platform for the exchange of balancing energy from manual frequency restoration reserves and from automatic frequency restoration reserves, respectively. (EUR-Lex 2019b) Intuitively, the Nordic TSOs are obliged to join these platforms in the future, but additionally, the upcoming Nordic energy activation platforms for manual and automatic FRR will respect the design principles of their European counterparts. This chapter will discuss the technical requirements and processes that are introduced in the all TSO proposals regarding the European manual frequency restoration reserve platform (MARI) and the European automatic frequency restoration reserve platform (PICASSO).

3.4.1 PICASSO

PICASSO is the project name for the implementation of the European platform for the exchange of balancing energy from aFRR. The electricity balancing guideline not only obliges the TSOs to develop a framework for the European aFRR platform but also specifically obliges the TSOs to harmonize certain features of aFRR products and processes. Thus, the all TSO proposal defines the specifications of the standard product, the gate closure time for the standard aFRR balancing energy product bids (BEGCT) and the gate closure time for the transmission system operators to submit the bids further (TSO GCT). In addition, the proposal introduces a high-level scheme of the aFRR platform and its main functions. (ENTSO-E 2018d)

The proposal considers minimum bid size, bid granularity, bid validity period and full activation time (FAT) as the specifications related to the standard product that are needed to be harmonized immediately from the start of the platform. Currently, the minimum bid size vary between 1 and 5 MW across Europe, but the TSOs preferred 1 MW as the minimum limit for the standard product. However, it can be revised, if the ICT-systems remarkably slow down due to the increment in the number of bids. The maximum limit will be set to 9999 MW. The bid granularity will be equal to 1 MW meaning that the smallest difference between two bids is allowed to be 1 MW. The validity period will be set to 15 minutes during which the TSO can accept a bid and request reserve resource activation from the balance service provider. Full activation time is also a feature that ranges broadly between the European countries: Some TSOs apply FAT of 2 minutes while others apply up to 15 minutes FAT. The TSOs have come to a conclusion that the standard aFRR energy bid must be fully activated in 5 minutes after the activation request. Lastly, the BEGCT will be set to 25 minutes and the TSO GCT to 10 minutes. After the first gate closure, the TSOs will form local merit order lists (LMOL) including the bids the BSPs have submitted. Then the TSOs send the lists to the European aFRR platform, which creates a common merit order list (CMOL) for all the European bids based on the LMOLs. These gate closure times assure an adequate lead-time for the common platform and TSO processes. (ENTSO-E 2018d)

The core of the aFRR platform is an activation optimization function (AOF), which receives inputs from the TSOs, that are controlling the LFC areas, and sends outputs towards the TSOs as exemplified in figure 14 below. The inputs include the aFRR demand per LFC area calculated by the relevant TSOs. The aFRR demand is calculated for each control cycle and it reflects the LFC area imbalance before any aFRR activation, but considers all the earlier processes that has been carried out for balancing purposes including, for example, mFRR activation. Along with the demand parameters, the AOF receives aFRR cross-border capacity limits, the local merit order lists discussed earlier and the operational security constraints from the TSOs that participate in the platform. In addition, the TSOs are responsible for updating the availability status of the bids: If an automatic frequency restoration reserve balancing energy bid suddenly becomes unavailable, it must be notified to the aFRR platform. After receiving all the required inputs from the participating TSOs, the AOF begins to determine the automatic frequency restoration reserve correction values for each LFC area. Following the optimization, the correction values are sent to the TSOs controlling the LFC areas. The sum of the correction value and the initial aFRR demand is the corrected demand for aFRR, which the LFC area itself has to take care of. (ENTSO-E 2018d)

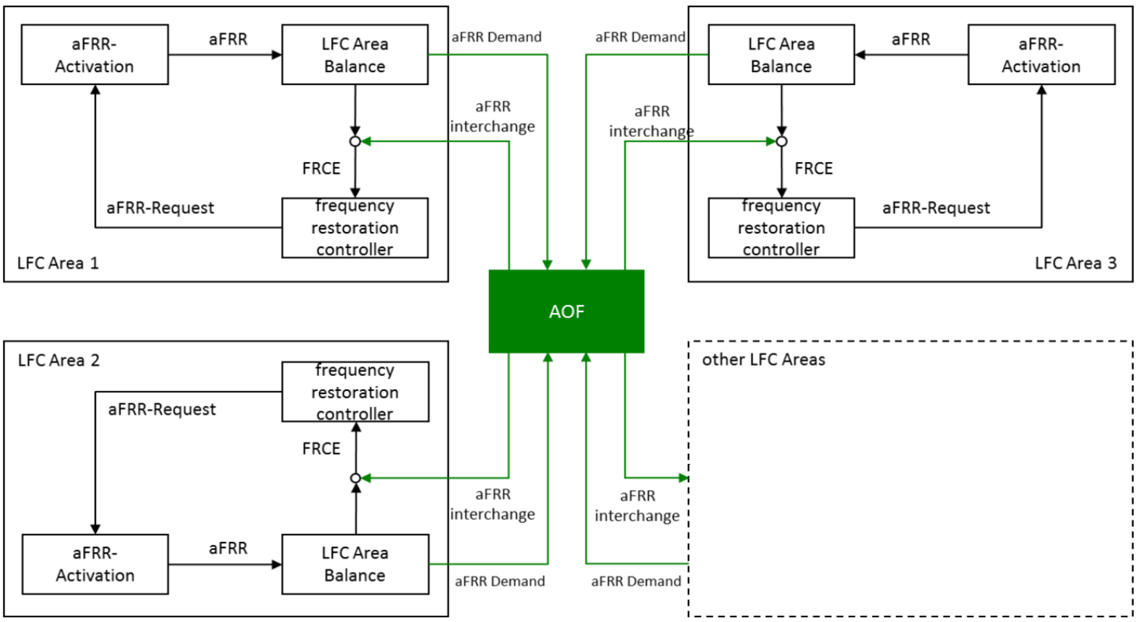


Figure 14: A high-level design of the European platform for automatic frequency restoration reserve (ENTSO-E 2018d).

3.4.2 MARI

The EBGL obliges the TSOs to develop a framework concerning the implementation of the European manual frequency restoration reserve platform, which is called MARI. The all TSO proposal, which aims to fulfil the requirements of the obligation, defines common business processes and governance principles as well as the technical details of the platform. Although the characteristics are integrated and harmonized, the TSOs can differ from each other in terms of activation philosophy: Some of the TSOs can take care of the forecasted imbalances by carrying out proactive processes while others may rely on reactive real time balancing, which has a significant influence on how the manual and automatic frequency restoration reserves are utilized. (ENTSO-E 2018c) This chapter will take a closer look at the standard product and process of the European mFRR platform.

The TSOs have come to a following conclusion concerning the specifications of the standard manual FRR product: The full activation time will be set to 12.5 minutes and the minimum delivery period duration is set to 5 minutes during which the balance service provider must deliver the full requested power. The bid size can vary between 1 and 9999 MW and the granularity will be 1 MW. The bids will have two activation types, which are scheduled activation and direct activation. The starting point of the scheduled activation is 7.5 minutes before the start of an operating quarter. After the starting point, the relevant BSP has 12.5 minutes of time to fully activate the power quantity of the bid. The BSP must deliver the full power for a minimum of 5 minutes. If a bid of the same BSP is not selected for delivery in the next operating quarter, the BSP must start to deactivate the bid, which should be completed within 12.5 minutes. The direct activation is otherwise similar, but the earliest starting point is 7.5 minutes before the start of an operating period and the latest starting point is 7.5 minutes after the start of an operating period. Briefly, the scheduled activation request from the TSO to the BSP takes place at a specific point in time, but the direct activation request can be sent more freely. Therefore, the scheduled activation product is typically utilized to release previously activated aFRR or to take care of forecasted imbalances proactively and the direct activation product is used to mitigate large imbalances within operating period. (ENTSO-E 2018c) Figure 15 below elaborates the shapes of the mFRR standard products. BSP GCT is the gate closure time for the bids submitted by the BSPs.

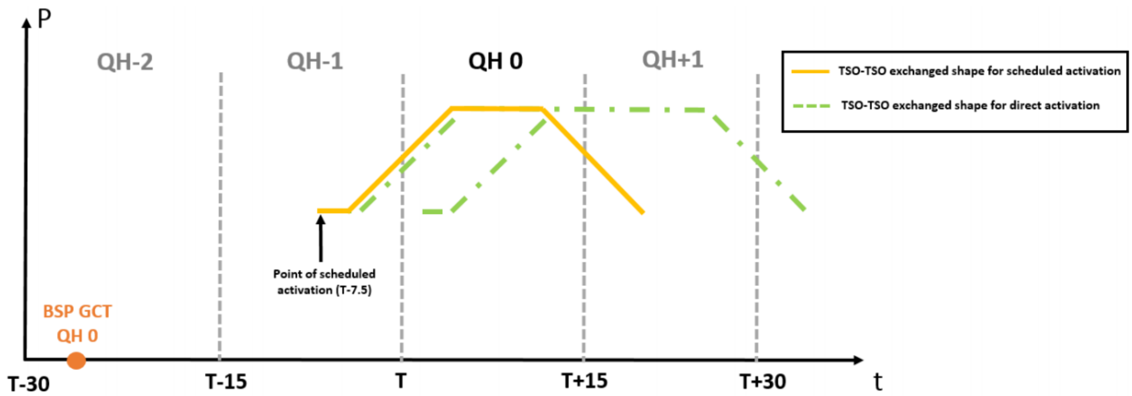


Figure 15: Example shapes of the scheduled and direct activation product types (ENTSO-E 2018c).

The activation optimization function (AOF) of the European manual frequency restoration reserve platform will follow two basic optimization principles. First, the AOF aims to maximize the mFRR economic surplus and second, it tries to minimize the exchange of mFRR on borders. The inputs that the AOF receives are the merit order lists including mFRR balancing energy bids collected by the TSOs, the balancing energy demands calculated by the TSOs and various constraints related to the system security and cross border capacity. Then, the AOF calculates an outcome that is feasible taking into account the set constraints and the optimization principles. The outputs include various data and, from the activation point of view, the most essential is the information concerning the accepted balancing energy bids and the satisfied balancing energy demands. After receiving the results from the European mFRR platform, the TSOs send the activation signals to the selected BSPs possessing the reserve resources. (ENTSO-E 2018c)

4 Balancing philosophy design principles

The upcoming changes related to the development of Nordic power system balancing will change the balancing responsibilities of each Nordic TSO and refine the incentives that direct the behavior of the balance responsible parties. Along with these modifications, the balancing product marketplaces and specifications will change, which influences the availability and usability of the balancing products. This chapter discusses how the various changes affect the balancing philosophy and design of Fingrid and the Finnish power system. First, the different market solutions are considered more closely. Second, the usability of production plans is analyzed. Third, the availability of frequency restoration reserves is speculated and lastly, the economic optimization point of view is dealt with. These principles determine the conclusions and recommendations that are given related to the future balancing philosophy of the Finnish power system.

4.1 Market solutions

4.1.1 Shortening of imbalance settlement period

One of the upcoming market changes is the implementation of 15 minutes imbalance settlement period (ISP) and market time unit (MTU), which are both 60 minutes currently. BRPs are financially responsible for their imbalances over the imbalance settlement period and thus, they try to achieve hourly balanced positions in order to avoid imbalance costs. However, during the operating hour, instantaneous imbalances take place, and these can net out over the 60 minutes period. If a BRP causes a negative and a positive imbalance during the hour, but they are equal in size, the cumulative imbalance is zero and therefore, the BRP will not face any costs due to the netting out of imbalances. (Copenhagen Economics 2017) Figure 16 below illustrates a real example of how large production imbalances can net out over the operating hours. The blue line represents actual electricity production in Finland in the morning of January 16, 2019 and the orange line represents the hourly production averages, which can be thought as the hourly scheduled production positions of the BRPs. The data for the actual electricity production is retrieved from Fingrid's open data website. As can be observed, deviations between actual production and scheduled hourly production positions presented in the lower graph take place continuously and the highest imbalance peaks are quite notable. However, the peaks net out over the hours, since the positive and negative deviations are equally sized within the hours. The lowest peak is -351 MW and the highest peak is 219 MW.

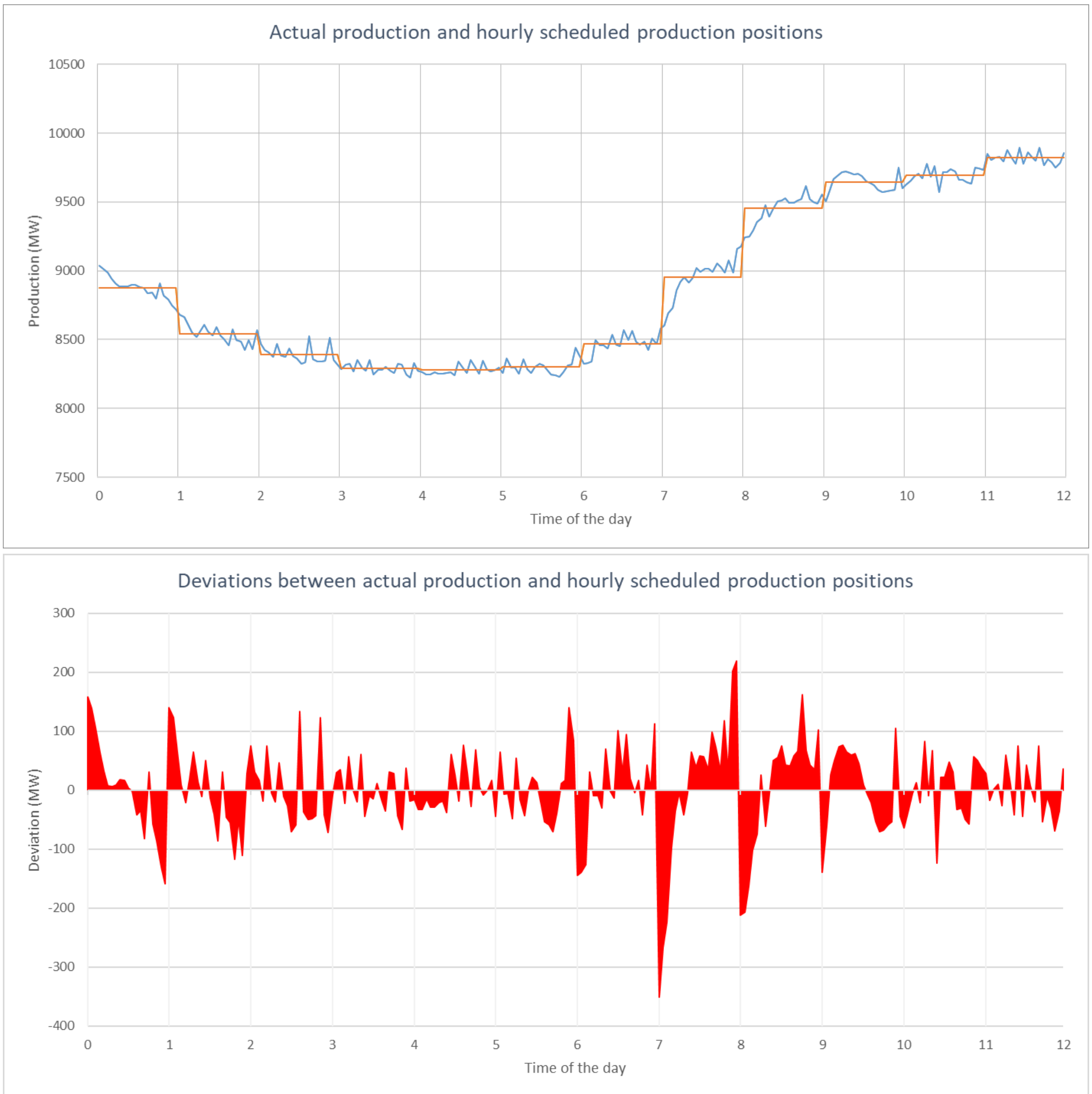


Figure 16: The blue line represents actual production, the orange line represents hourly scheduled production positions and the red line represents the deviations between the two in Finland between 00:00 – 12:00 in the morning of January 16, 2019.

The introduction of 15 minutes imbalance settlement period will change the situation as the imbalances netting out over the hour period will become visible with the 15 minutes ISP. Therefore, the BRPs will face imbalance costs, if they continue to take positions on hourly basis. On the other hand, they can refine their behavior and start taking quarterly positions and as a result, they can avoid the newly settled imbalance costs. With quarterly system, the netting out of positive and negative imbalances is reduced. (Copenhagen Economics 2017) Figure 17 below illustrates a real example of how large deviations can net out over the operating quarters. The blue line represents actual electricity production in Finland in the morning of January 16, 2019 and the orange line represents the quarterly production averages, which can be considered as the quarterly scheduled production positions of the BRPs. The actual production data is retrieved from Fingrid's open data website. Similarly as in the figure with hourly averages, the red area illustrates the deviations between the actual production and quarterly averages. Now the lowest peak is -156

MW and the highest peak is 159 MW. Thus, with quarterly scheduling the instantaneous imbalances will decrease as the operating period shortens and the possibility for netting out of energies lowers.

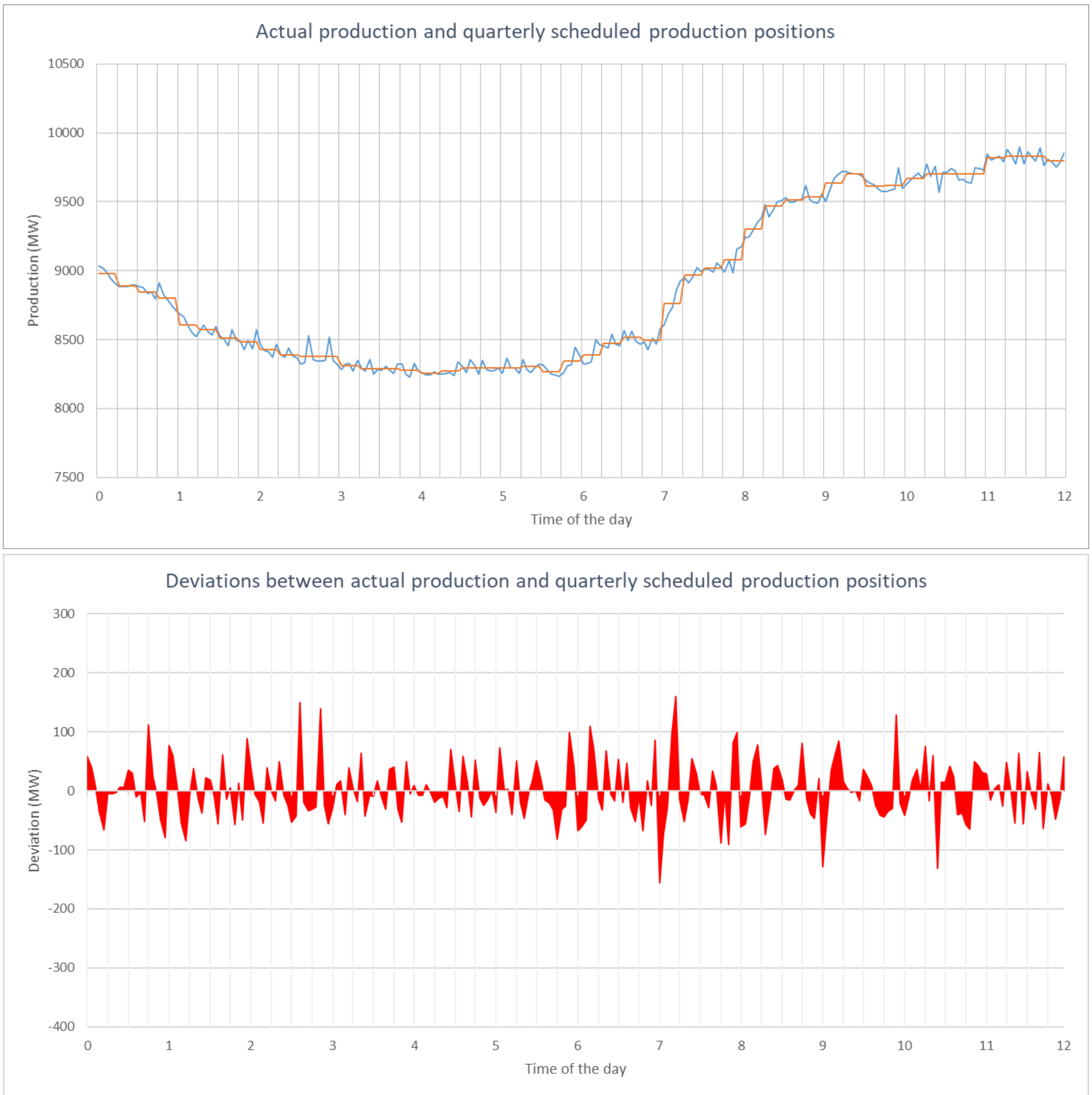


Figure 17: The blue line represents actual production, the orange line represents quarterly scheduled production positions and the red line represents the deviations between the two in Finland between 00:00 – 12:00 in the morning of January 16, 2019.

The introduction of 15 minutes resolution will be beneficial from the system balancing point of view as the netting out of imbalances will decrease and the imbalance settlement will be more in line with the actual imbalances. However, it should be noted that the above example does not reflect perfectly the imbalances taking place. Firstly, the instantaneous power system imbalances do not happen only because of the actual production deviating from the scheduled production, since the imbalances are also dependent on the actual consumption. Although the example shows that the largest deviation peaks between actual production and scheduled production positions can be reduced by over 50

%, this does not mean that the imbalances decrease the same amount. Secondly, the example assumes that the BRPs will and are able to schedule their production and take positions on quarterly basis, which is not necessarily true. The incentives that come from the imbalance settlement, however, encourage the BRPs to do so, because otherwise they will face imbalance costs.

Along with the reduction of netting out of imbalances, the introduction of 15 minutes time resolution will entail other advantages too. The net system imbalances will decrease between 1.5 to 6.1 % in the Nordic power system. The lowest rate assumes that the BRPs will trade away 25 % of the newly settled imbalances on the intraday market and the highest rate assumes that all the newly settled imbalances are traded. Instead of the intraday trading, another option for the BRPs is to adjust their flexible production or consumption in order to tackle the imbalances. In addition to the lower net system imbalances, the jumps between balance positions will become smaller when the balancing period shortens from 60 to 15 minutes. In Finland, the jumps around period shifts will reduce approximately 23 % and the reduction will be most remarkable in situations in which the sizes of the jumps are highest, for example during morning hours when production and consumption are ramping up. (Copenhagen Economics 2017) All in all, with 15 minutes ISP and MTU the market participants are able to achieve balanced positions and handle their expected imbalances in a more accurate manner, since the balancing horizon shortens and the BRPs have better understanding about the upcoming period of operation. Moreover, the balance positions of adjacent periods are closer to each other when the length of balancing period is 15 minutes instead of 60 minutes, which smooths system operations.

As mentioned above, the possibility for large jumps reduces when the balancing and production scheduling timespan shortens. This is exemplified more closely in figure 18 below. The data for actual production is retrieved from Fingrid's open data website. The illustrative example in question shows that the gap between hourly positions is 498 MW. The same gap decreases down to 226 MW when the positions are taken on quarterly basis and the other jumps are even smaller. The highest jump is reduced by more than a half, which eases system operation as the changes between balancing periods are steadier than before. It should be noted that the figure only illustrates limited sample of actual production in a January morning and thus, the results of this examination are only suggestive. For example, during afternoons the reduction of jump sizes may not be that significant. In addition, the analysis is based on actual production that has taken place when the ISP has been 60 minutes and thus, the production pattern represents hourly operation. As can be observed, at the beginning of both hours the production ramps up and then stabilizes, which is common behavior on hourly system. Therefore, when 15 minutes ISP is introduced, the profile of the production curve will supposedly change to represent quarterly system: In the beginning of each quarter, there may appear a slight ramp up and then again, the profile flattens out. However, it is evident that the sizes of the jumps will decrease.

Figure 18: In both graphs, the blue line represents actual production in Finland between 07:00 – 09:00 in the morning of January 16, 2019. In the upper graph, the orange line represents hourly scheduled production positions, whereas in the lower graph the orange line represents quarterly scheduled production positions.

The length of imbalance settlement period is one of the key design variables related to proactive and reactive balancing market designs. Håberg & Doorman (2016) have discussed different balancing activation philosophies and the influence of imbalance settlement period on them in Northern European area. Their study states that short imbalance settlement period supports reactive designs, whereas long ISP leaves room for the TSOs to proactively make decisions about balancing product activation.

There are quite a few reasons why reactive designs are joint together with shorter imbalance settlement periods. Some of the reasons are discussed above: Firstly, the reduction in netting out of imbalances results in lower balancing necessities inside the operating periods and thus, the needed reactions can be slighter and the balancing volumes smaller. Secondly, the net system imbalances will reduce, which lowers the need for balancing actions further as the BRPs can adjust their positions more accurately closer to real time. Thirdly, the consecutive positions of the BRPs will be closer to each other as the period shortens. This decreases the size of position jumps, which eases system operations and the TSOs do not need to reckon with large changes proactively. Along with these aspects, the shift from 60 to 15 minutes imbalance settlement period works as an indicator that the transmission system operators are willing to give more responsibility for the balance responsible parties regarding balancing. Short ISP ensures that the BRPs will contribute more efficiently to the balancing process as the quarterly settled imbalances and price signals will encourage the BRPs to adjust positions more frequently. This together with the shortened planning horizon will improve the accuracy and performance of market behavior of the BRPs and thus, the need for proactive TSO procedures declines.

4.1.2 Change of imbalance settlement model

The current imbalance settlement model, which is based on calculating and settling production and consumption imbalances separately, will be updated to single position model. In addition, single pricing will be applied to the single position. These changes mean that a single imbalance volume calculation will include both production and consumption and the production plans will not be included in the calculation. Additionally, the prices for positive and negative imbalances will be identical. (Fingrid 2019g)

Nowadays the model of two separate imbalances incentivizes balance responsible parties to submit accurate production plans of a good quality to the TSOs and to follow the production plans as precisely as possible. Balance responsible parties that deviate from the scheduled production will not gain any extra profit compared to day-ahead trading, but instead they will expose themselves to a risk of additional costs. Thus, the imbalance pricing mechanism has not incentivized the BRPs to aspire intentional production imbalances – not even in the correct direction in order to help the system with imbalance mitigation. Since the TSOs have had rather good understanding about the operations of BRPs during the upcoming period of operation based on the binding production plans, they have been able to determine the utilization and activation of balancing products proactively.

After the introduction of the new single price and single position model, the financial incentives will change and therefore, the BRP cost optimization concerning the production and consumption portfolio will be affected. The new model encourages BRPs to operate their adjustable production or consumption so that they can cause imbalances over the imbalance settlement period as long as they are in the main regulation direction. This way the BRPs can help the TSOs to manage system imbalances and simultaneously make more profit than with the current settlement and pricing model (van der Veen et al. 2012).

This naturally affects the way in which the system should be balanced as the new settlement and pricing model will make it harder to predict the BRP behavior in advance. BRPs need to submit production plans to the TSOs as before, but they are not financially binding and deviations from the plans can be economic over the imbalance settlement period. This means that the relevance of the production plans will lower, since the BRPs might want to cause imbalances intentionally, i.e. exercise self-balancing. As the prognosis model of the upcoming operating period presented in chapter 3.3 relies on the BRP production plans, the proactive decision-making of the TSOs concerning balancing will lose ground. The production plans will only be the best guess of how the market participants will behave, but actually, the BRPs may want to operate differently depending on the underlying profits. Figure 19 below shows how the activation philosophies of the TSOs are linked to the BRP incentives in northern European area. Stronger incentives for the BRPs support reactive balancing design and with weaker incentives, the balancing is more in the hands of the TSOs, which can proactively determine the activation of balancing products before the operating period. The changes related to the imbalance settlement will strengthen the BRP incentives and Fingrid should promote reactive activations based on the figure below.

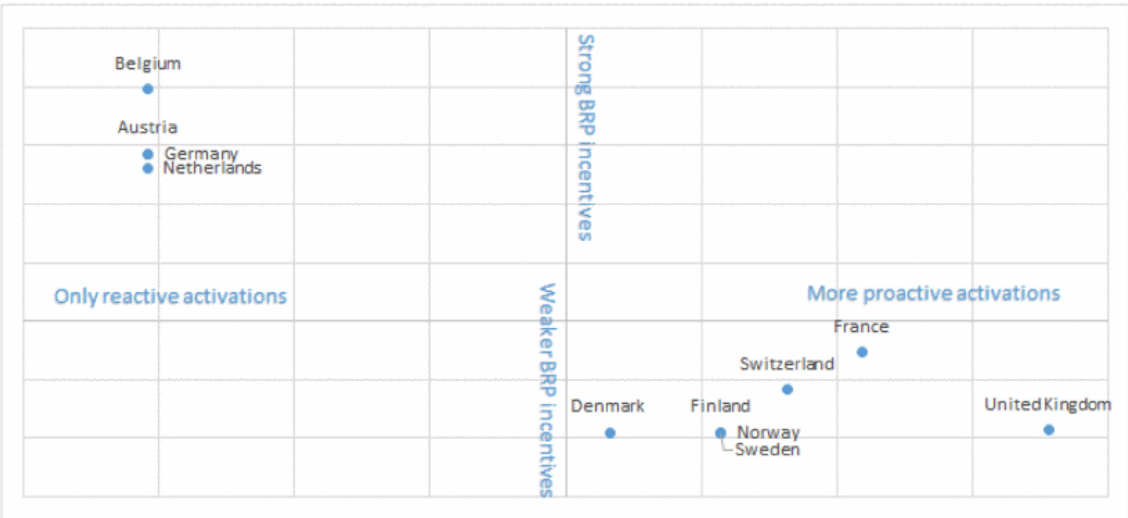


Figure 19: Interdependence between TSO balancing design and BRP incentives (Håberg & Doorman 2016).

A few aspects, however, are limiting the degree of intentional imbalances of the BRPs. Firstly, the size of a BRP has an influence on the profitability of self-balancing. Large BRPs can affect the system imbalance more than smaller BRPs, and thus, the large players can make less profit from single price mechanism than their smaller counterparts when having imbalances in the correct direction (van der Veen et al. 2012). This indicates that the volume of self-balancing during the operating period is restricted by the markets, since the profitability of imbalances decrease when the capability to cause them increases. Secondly, legal obligations are limiting the behavior of the BRPs. In order to take full advantage of the self-balancing effectively, the BRPs should have legal permission to help the system with their intentional imbalances (Hirth & Ziegenhagen 2015). However, in the Nordics the BRPs have a balance obligation (eSett 2019). This means that they must try to hold balanced positions on regular basis and therefore, self-balancing is against the rules. Third aspect to be considered is the availability of real time balancing information. If the BRPs are willing to cause imbalances in the right direction, it requires knowledge of balancing direction, volumes and prices. High uncertainties related to the direction and prices decrease the attractiveness of choosing intentional imbalances as a strategic path (Schraff & Amelin 2016). In the Nordics, the balancing prices and volumes are not published in real time, but instead 60 minutes afterwards on Nord Pool website (ENTSO-E 2016). Thus, the BRPs will face a risk of additional costs, if they primarily try to achieve imbalanced positions, which reduces the incentive to behave in such a manner. Lastly, as discussed in chapter 3.1.4, the transmission system operator may apply dual pricing, if the self-balancing of the BRPs is too overpowering. This should restrict the BRP behavior and prevent major mistakes. In addition, it should be noted that if the imbalance prices do not differ from the day-ahead market price significantly, the incentives are not strong enough to direct the operations of the BRPs.

Even though the shift to single position and single price model can lead up to uncertainty concerning the operations of the BRPs, the above-mentioned aspects restrict intentional imbalances. It seems that the publication of real time balancing information is very central when considering the influences of single price model on the TSO activation philosophy. If the TSOs continue to publish relevant balancing information afterwards, the production plans of BRPs might represent their behavior quite well also in the future, which supports the proactive decision-making and activation of the balancing products beforehand the operating period. On the other hand, without proper real time understanding, the BRPs may act in a false manner. If the TSOs improve the availability of the real time balancing data, the BRPs can support system balancing and the TSOs can rely on reactive balancing actions as the BRPs will chase after positions that support the whole system. Undoubtedly, the BRPs may overreact to the signals, but then the feedback loop based on the incentives should refine the behavior of the BRPs as they should see how their behavior influences on the imbalance costs.

4.1.3 Intraday market development

Along with the market changes that are implemented due to the electricity balancing guideline (EBGL), intraday market will undergo modification in Finland. Intraday trading can be seen as a profitable business, since it allows the market participants to trade away imbalances and therefore, to decrease imbalance costs. Expected imbalance costs correlates with the willingness-to-sell and willingness-to-buy of the market participants and with intraday trading BRPs can hedge against volatile imbalance prices, which can be seen as the main motivation for entering intraday markets (Schraff & Amelin 2016).

From the TSO and balancing point of view, intraday market trading is central. The Nordic synchronous system is under a reformation of production palette as the conventional and adjustable production facilities are phasing out from the system and they are substituted by variable renewable energy sources (vRES), especially wind power. On average the forecasts related to the intermittent production become more precise when getting closer to real time as the forecast horizon shorten and the weather forecasts and measurements provide more accurate data. Thus, the market participants have better understanding about their scheduled production and supposed deviations on intraday market than on day-ahead market, and they can perform trading in more exact manner. Therefore, well-functioning intraday markets can decrease the volume of activated balancing services (Schraff & Amelin 2016).

Recent discussion in Finland has brought out possible intraday market developments that could take place in the near future. Nord Pool has made a proposal for changing the intraday gate closure time together with the implementation of 15 minutes imbalance settlement period. The change could be introduced in Finland as there are no legislative restrictions concerning internal trading in a bidding zone. The proposal suggests that the intraday gate closure time for internal trading could be 0 minutes, which enables trading of energy as close to real time as possible. (Fingrid 2019h) This change is likely to get support from market participants who utilize intraday market to trade away imbalances and aim to reach balanced positions, for instance, according to wind power forecasts that become more accurate closer to real time as the forecast horizons shorten. On the other hand, for some thermal power plants the rescheduling of production can be limited and bring additional costs, if it takes place just before the gate closure. Nonetheless, most of the intraday trades occur just a few hours before the period of delivery in the Nordic region, although the market is continuous. (Schraff & Amelin 2016)

Trading activity of Finnish market participants is illustrated in figure 20, which shows how the intraday trades has taken place before the delivery period in Finland in 2018. The highest peak represents intraday trading just before the cross-zonal gate closure time, which is 60 minutes before the delivery in Europe. The second highest peak represents the trading just before the intraday gate closure of Finland-Estonia border, which is, exceptionally, 30 minutes before the delivery. It can be interpreted from the figure that the Finnish market participants are most active just before the gate closures. This indicates that there exist a demand for energy trading closer to real time, which could support power system balancing and lessen the need for balancing product activation as the BRPs could balance themselves in a more accurate manner.

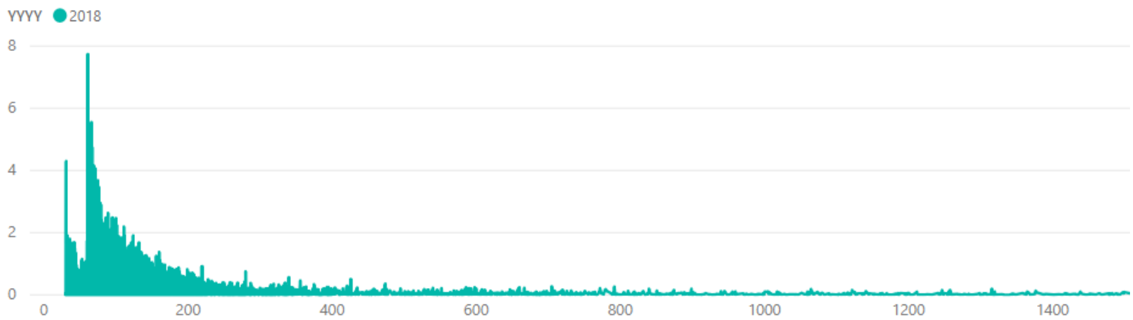


Figure 20: Volume of intraday trading in GWh as a function of minutes before the delivery of energy in Finland in 2018 (Fingrid 2019h).

As mentioned, well-designed intraday market can support power system balancing and decrease the volume of activated balancing products. However, a few aspects reduce the potential of intraday trading to support system balancing. As the trading is dependent on the willingness-to-sell and willingness-to-buy of market participants, the trades that take place should benefit both the buyers and the sellers. Schraff & Amelin (2016) investigated in their study the trading behavior of market participants on the Nordic intraday market. A part of the study brought out a result indicating that a two-price system is more beneficial for the market participants than a one-price system, if the market participants do not refine their market behavior. This is based on the assumption, that the market participants only enter the intraday markets in order to decrease their expected imbalance costs and in addition, they are risk-neutral and have mutual understanding about the expected balancing direction and prices. In such a situation, the buyer would like to purchase energy at a price that is lower or equal to the expected balancing price. On the other hand, the seller is willing to sell, if the price is at least the expected balancing price. Thus, the equilibrium price equals to the expected balancing price, which decreases the attractiveness of intraday trading as no additional profit can be gained. However, these assumptions rarely hold true in the real world. Along with the imbalance cost reduction, the market participants might have other underlying motivations, such as the possibility to optimize own production and consumption facilities, if their variable costs are higher compared to buying energy from the intraday markets. In addition, the market participants are not always risk-neutral so they may be willing to add risk premiums to the prices. Lastly, the understating about balancing prices and direction may differ and thus, the market participants trade with different expectations.

Another aspect, which restricts the benefits related to the intraday trading, is the lack of recent knowledge of balancing situation. Market participants have limited and varying capability to form expectations of the upcoming balancing prices and volumes and hence, they are exposed to considerable uncertainties. This has two influences on the intraday trading. Firstly, the threshold to enter the market is higher as the profitability is precarious and secondly, there exists a time lag that restricts the balancing benefits from the system point of view. The latter means that intraday trading is prone to react with some delay to the balancing situation and price development and therefore, the trading on intraday market do not directly reflect the change in the balancing situation and the actions of market participants do not support the system balancing as efficiently as they could. (Schraff & Amelin 2016) One key enabler in order to improve intraday trading is to publish balancing prices earlier. Balancing information transparency would ensure a level playing field for all the market participants and in addition, the market actions would help TSOs with system imbalance mitigation as the trading could react to the balancing situation changes and price development in a more agile manner.

Overall, the shortening of intraday gate closure time is a step having an influence on the balancing responsibility. It creates a possibility for the BRPs to achieve balance until the start of an operating period, which reduces the need for proactive balancing product activation, since the imbalances are handled by market-based actions of the BRPs. A few aspects, however, may more or less obstruct the last-minute intraday trading as discussed above, but at least shortening of the gate closure time works as an indicator for the BRPs that the relevant TSO is willing to rely on the market participants and solutions. This increases the responsibility of the BRPs, but on the other hand, they can utilize their assets more efficiently and potentially yield more profit. Reactive balancing designs are characterized by intraday gate closure times equal to zero, whereas proactive TSOs support a gap between gate closure time and real time in order to ensure sufficient leeway for determining necessary proactive balancing product activations (Håberg & Doorman 2016). By letting the BRPs to control imbalances up to the last minute, the relevant TSO needs to carry out only reactive balancing actions in order to take care of the stochastic imbalances occurring during the period of operation.

Another possible solution to realize the potential and benefits of intraday trading from balancing perspective is to introduce intraday auctions. As the Nordic intraday market tends to have rather low liquidity, auctions might improve the situation. Scharff & Amelin (2016) have brought out an observation, that the intraday trading is most likely done manually and not all the participants follow the market round the clock in the Nordics. In addition, more active monitoring increases transaction costs, but simultaneously the probability of trading profitability rises. Moreover, large price variations take place on the intraday market. To overcome these flaws, they suggest that a discrete intraday auction with marginal pricing should be analyzed more profoundly and the possible benefits should be discussed. For instance, Spanish intraday market has succeeded to lower the trading price risk and reduce the overall transaction costs by including six auctions during the day of delivery (Weber 2010). It is noteworthy, that the Spanish intraday market has considerably high trading volumes compared to the other intraday markets in the EU area (Chaves-Ávila & Fernandes 2015). Thus, the introduction of auctions might possibly improve the liquidity of intraday market, as the trading would be more sensible for the market participants. This, in turn, would benefit the whole system as the BRPs would have better market tools to trade away imbalances and therefore, they would be balanced more precisely before the real time operation, which would lessen the need for proactive TSO balancing.

The German example has shown how the well designed and well-functioning short-term wholesale electricity trading has successfully contributed to the reduction of balancing reserve utilization. Between years 2011 and 2017 the installed capacity of solar and wind power has increased from 54 GW to 99 GW in Germany. As these generation forms produce electricity intermittently depending on the weather circumstances, the operational forecasts related to them are not perfectly accurate. Thus, it is well justified to assume that such a remarkable increase in wind and solar power capacity would have increased the need for balancing product activations and capacity procurement. However, the total amount of frequency restoration reserves procured by the German TSOs has decreased 20% between 2011 and 2017. In addition, the activation of frequency restoration reserves has decreased from well above 7 TWh in year 2011 to 2.5 TWh in year 2017 as presented in figure 21 below. Simultaneously, the ratio of mFRR to aFRR has changed, since the usage of mFRR has shrunk near to zero. Such changes has been possible partly because of the improved international cooperation of TSOs, which includes imbalance netting, but this aspect alone does not explain the reduction in the procurement and activation of frequency restoration reserves, because simultaneously the electricity market activities have developed remarkably. (Koch & Hirth 2018)

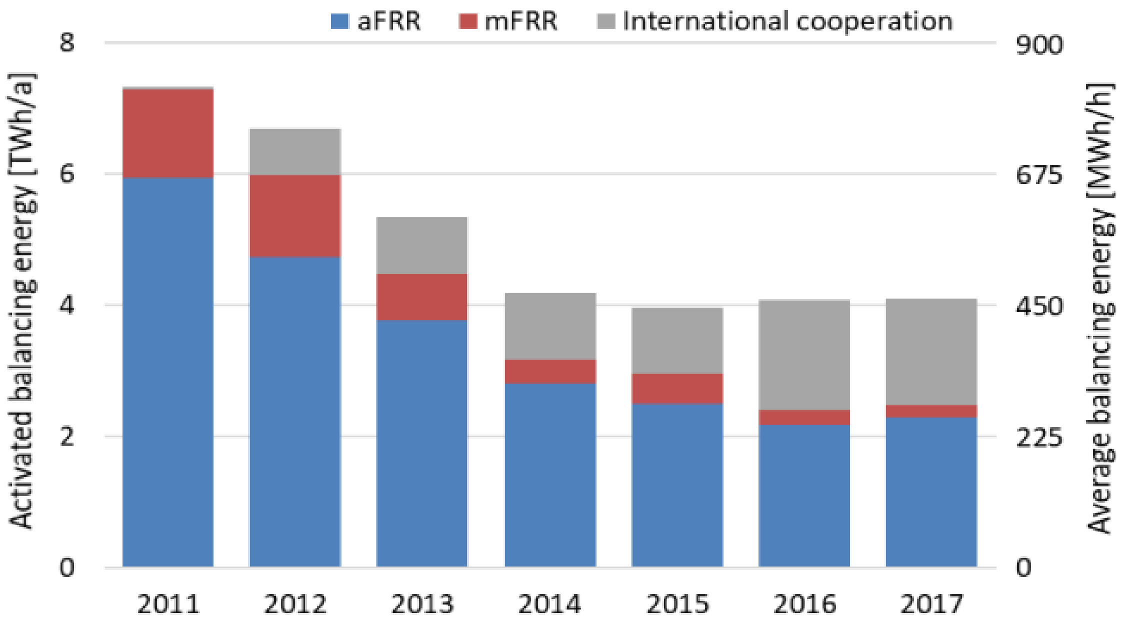


Figure 21: Activated balancing energy in TWh in Germany during 2011-2017 (Koch & Hirth 2018).

The above-mentioned German balancing paradox suggests that market-based solutions are working efficiently and they have improved the balancing situation. One of the key changes has been the development of intraday market: The trading volumes have increased quickly while the reserves activated by TSOs has declined. The growth of yearly trading volume has been more than 600% from 2012 to 2017 as shown in figure 22 below. On the German intraday market the gate closure of the continuous trading takes place 30 minutes before real time. After that starts an extended trading, which is open until 5 minutes before real time. The extended trading is, however, possible only within a balancing area, of which there are four in total in Germany. Along with continuous trading, there is also intraday auction that was introduced in December 2014. The intraday auction has achieved a dominant position in terms of trading volume as more than half of the volume was traded on the auctions in 2017. Simultaneously as the volumes have increased, trading round the clock and closer to real time has become more popular, which can be observed especially during off peak times, such as nights and weekends. (Koch & Hirth 2018) Well-functioning intraday market together with quarterly products and 15 minutes imbalance settlement period has succeeded to reduce deterministic imbalances in Germany. Proper incentives and market design perform as an efficient tool for balancing, which shifts the balancing responsibility from the TSOs to the market participants. Thus, the TSOs do not need to involve themselves in proactive balancing, because the system can rely on market-based solutions and the BRPs are balanced more accurately.

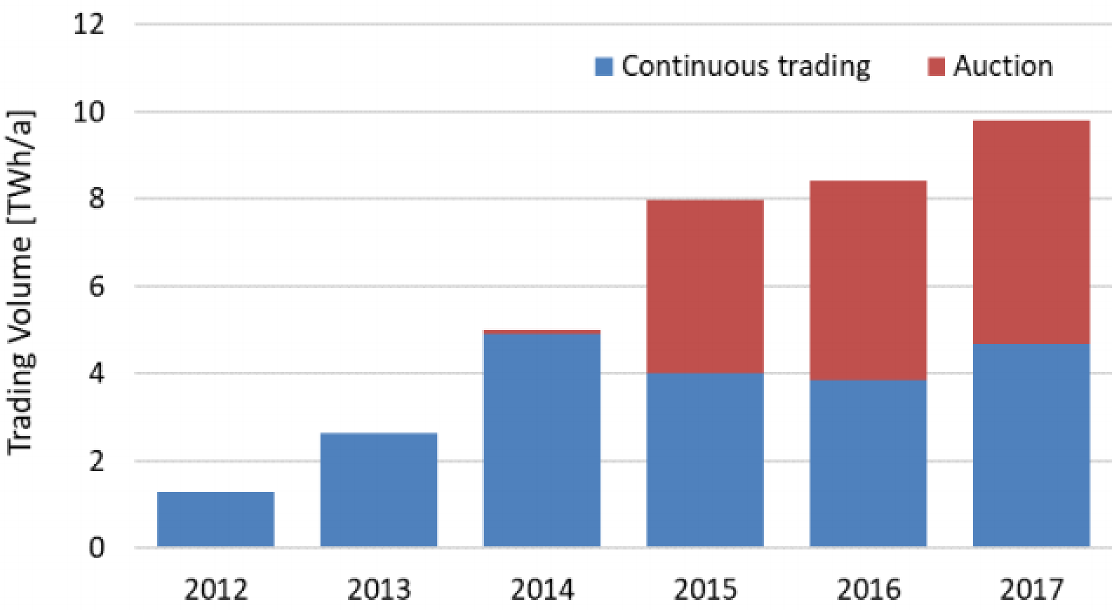


Figure 22: Yearly intraday trading volumes in TWh in Germany (Koch & Hirth 2018).

4.2 Usability of production plans

The ongoing balancing process in the Nordic synchronous system is highly dependent on various data, which helps the TSOs to forecast upcoming events within the operating periods. The information available beforehand is utilized as a basis for proactive decision making regarding system balancing and therefore, for instance, the TSOs are able to determine the volume and direction of manual frequency restoration reserve that needs to be activated proactively. Production plans are a corner stone of the planning and the TSOs receive them from the balance responsible parties well in advance. Production plans will also be a part of the imbalance prognosis that is calculated for every upcoming balancing period in the future when ACE-based balancing model is introduced. This chapter will discuss the usability of production plans in the future more profoundly, since it has an influence on the balancing philosophy.

One intuitive aspect related to the usability of production plans is to consider the errors they tend to contain. Especially interesting is to study if the volumes of the deviations between actual production and production plans have grown due to the increase in intermittent and weather-dependent production. According to Chang et al. (2013) the existence of prediction errors is one of the greatest challenges that arise from increasing the penetration of wind power in power systems. The prediction errors can vary from 25 to 40 % of the installed wind power capacity at the highest when forecasting is made for the day-ahead market trading purposes. This indicates that the system level deviations between planned production and actual production should increase synchronously with the growth of wind power capacity and production.

Wind power capacity and production have multiplied in Finland during the past decade as shown in figure 23 below. In year 2009 the capacity was 146 MW and the volume of production was 277 GWh. In year 2018 the same numbers were 2041 MW and 5857 GWh, respectively. Thus, the growth of wind power has been considerable: The capacity has increased more than ten times and the production volume has increased more than twenty times in ten years. Wind power accounted for 9 % of the total electricity production in Finland in 2018. (Energiateollisuus 2019a) If these numbers are evaluated from the balancing point of view, one could suggest that wind power has had some influence on the deviations between actual production and planned production on system level. If the above-mentioned error range is applied, the wind power prediction errors varied from 510 MW to 816 MW at the highest in year 2018. Naturally, it should be noted that solar power is also intermittent and weather-dependent production and similarly it is prone to prediction errors. However, solar power accounted only for 0.2 % of the total electricity production in Finland in 2018 (Energiateollisuus 2019a). Thus, it is well justified to leave solar power out of further discussion.

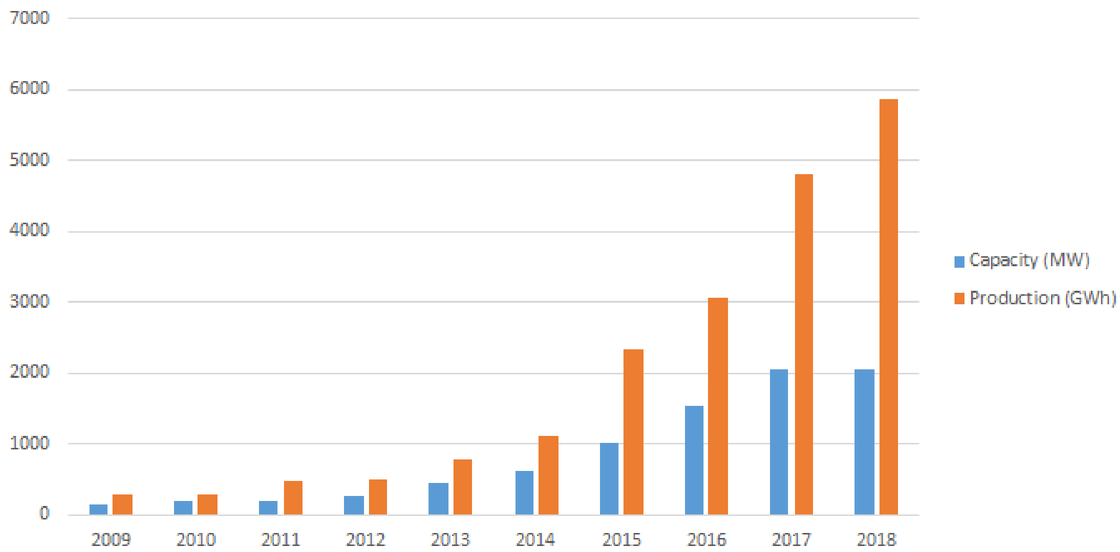
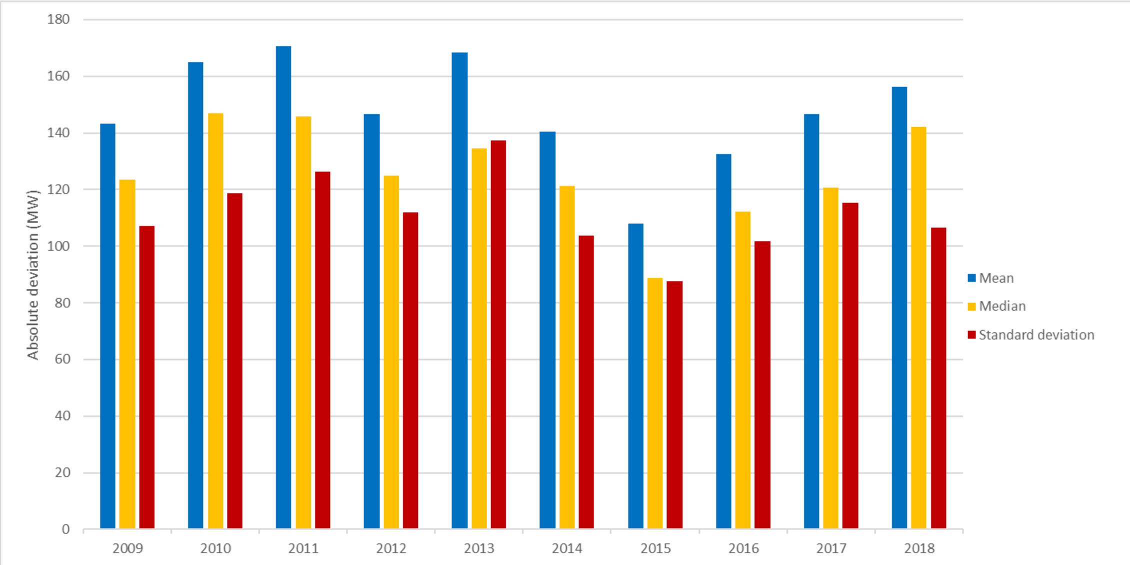


Figure 23: Installed wind power capacity in MW and yearly wind power production in GWh in Finland (Energiateollisuus 2019a).

In order to examine the differences that have taken place between planned and actual production on system level in Finland, planned production and production imbalance adjustments need to be subtracted from actual production on hourly basis. The result of this calculation is the total prediction error of the production in Finland, which is actually the same as the production imbalance power. Appendix A shows the calculated deviations for the time gap from 2009 to 2018. The production imbalance adjustments that are taken into account include FCR-N and both manual and automatic frequency restoration reserves. FCR-D, which also belongs to the frequency containment reserves, is ignored, since it is activated rarely and there is no easily accessible and relevant data available. The data utilized is retrieved from Fingrid's open data website and Fingrid's internal data systems. The largest deviation peaks are filtered out of the results as in most of the cases they are only computational faults due to poor data quality. To compare the years with each other, figure 24 below shows some annual key figures that are calculated based on the absolute values of the deviations. Mean is the central number of the values and it can be understood as the expected value. Median is the value, which separates the lower half of the results from the higher half. Standard deviation quantifies how spread out the values are, i.e. how far away the values tend to be from the mean. Cumulative distribution function pictures how likely a random deviation will be less than or equal to a value chosen from the x-axis. If the function increases steeply, the probability of small deviations is high and if the function rises gently, the probability of large deviations is high.



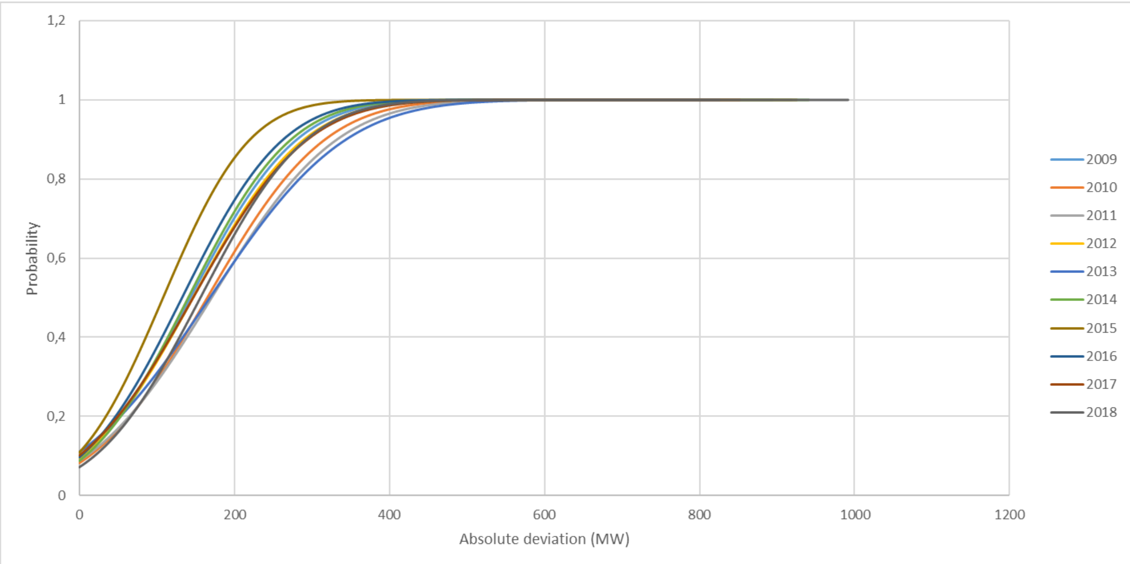


Figure 24: The upper graph represents the key figures and the lower graph represents the cumulative distribution functions of the absolute deviations between planned production and actual production in Finland between 2009 and 2018.

The graphs above show that between 2009 and 2018 in Finland there have been some fluctuations in the key figures, but the changes have not followed a distinct trend. Over the first five years, the key figures remained almost unchanged or increased slightly.

Thereafter the decline in key figures took place and 2015 was the year of lowest key figures. From this moment onwards, mean, median and standard deviation increased every year, except the standard deviation of 2018 diverted from the growth trend. Thus, there is no clear and unambiguous trend for change, which could be easily observed from the sample. However, all of the key figures have declining trend lines, which indicates that the deviations between production plans and actual production have decreased on average between 2009 and 2018 in Finland.

According to the above examination, it is not justified to assume that the increase in wind power capacity and production have weakened the usability of production plans on system level in Finland. However, there are a couple of underlying aspects that need to be considered. First, the imbalance settlement model, which was introduced in 2009, emphasizes production planning, since the model creates an incentive for the BRPs to generate and submit accurate hourly plans and to stick to them to the best of their ability. By minimizing the deviations between production plans and actual production, the BRPs can hedge themselves against imbalance costs and on the other hand, even if the imbalances are to the right direction and support the system, the BRPs do not gain any extra profit. Hence, there have been interests to compensate occurring prediction errors with adjustable generation in real time and to develop better prognosis systems in order to create more accurate predictions.

Secondly, due to the nature of the examination, extreme occasions and highest peaks are not paid much attention. Wind power production may increase the number of extreme deviations between actual production and production plans, but based on the above examination alone it is hard to say if this is true or not – at least the increment in wind power has not increased the deviations on average. The extreme occasions are hardest from the system balancing point of view and the influence of wind power on them could be investigated by calculating the deviations between planned and actual wind power production and comparing the results with the above examination, which represents Finland's whole production fleet. This would show if the system level deviation peaks are caused by wind power.

Third, forecasting of wind power production has gained much attention due to the expansion of wind power capacity in recent years and therefore, research and development related to wind power predictions have been very active (Foley et al. 2012). By utilizing advanced methods, it has been possible to create considerably better wind power predictions compared to the older forecasting models (Jung & Broadwater 2014). Thus, between 2009 and 2018 the amount of wind power has multiplied, but simultaneously the prediction models have become more advanced and accurate.

Fourth, all of the years have been different in terms of weather circumstances, consumption, availability and usage of production et cetera. Thus, it is hard to prove what the effect of wind power is as there are so many other things influencing on the power system operations. On the other hand, if wind power production does not stand out despite the other affecting aspects, then its effect can be considered insignificant.

Fifth, the examination do not take into account the changes in annual electricity production, which has varied between 2009 and 2018. For example, in 2010 the total electricity production was 77.2 TWh whereas in 2015 the same number was 66.1 TWh (Energiateollisuus 2019b). This in turn can partly explain why the deviation key figures were higher in 2010 than in 2015 – presumably higher production rates result in higher deviations. Sixth, the accuracy of this examination in question is varying. Some of the datasets had rather low quality as there were time gaps missing the relevant data. Thus, the blanks needed to be filled with approximated values, which may have skewed the results.

Another interesting aspect related to the usability of production plans is the occurrence nature of the deviations between production plans and actual production. Figure 25 below includes two graphs: The upper one represents how the deviations have occurred on average per operating hour between 2009 and 2018 and the lower graph shows the average electricity production power per operating hour for the same time period.

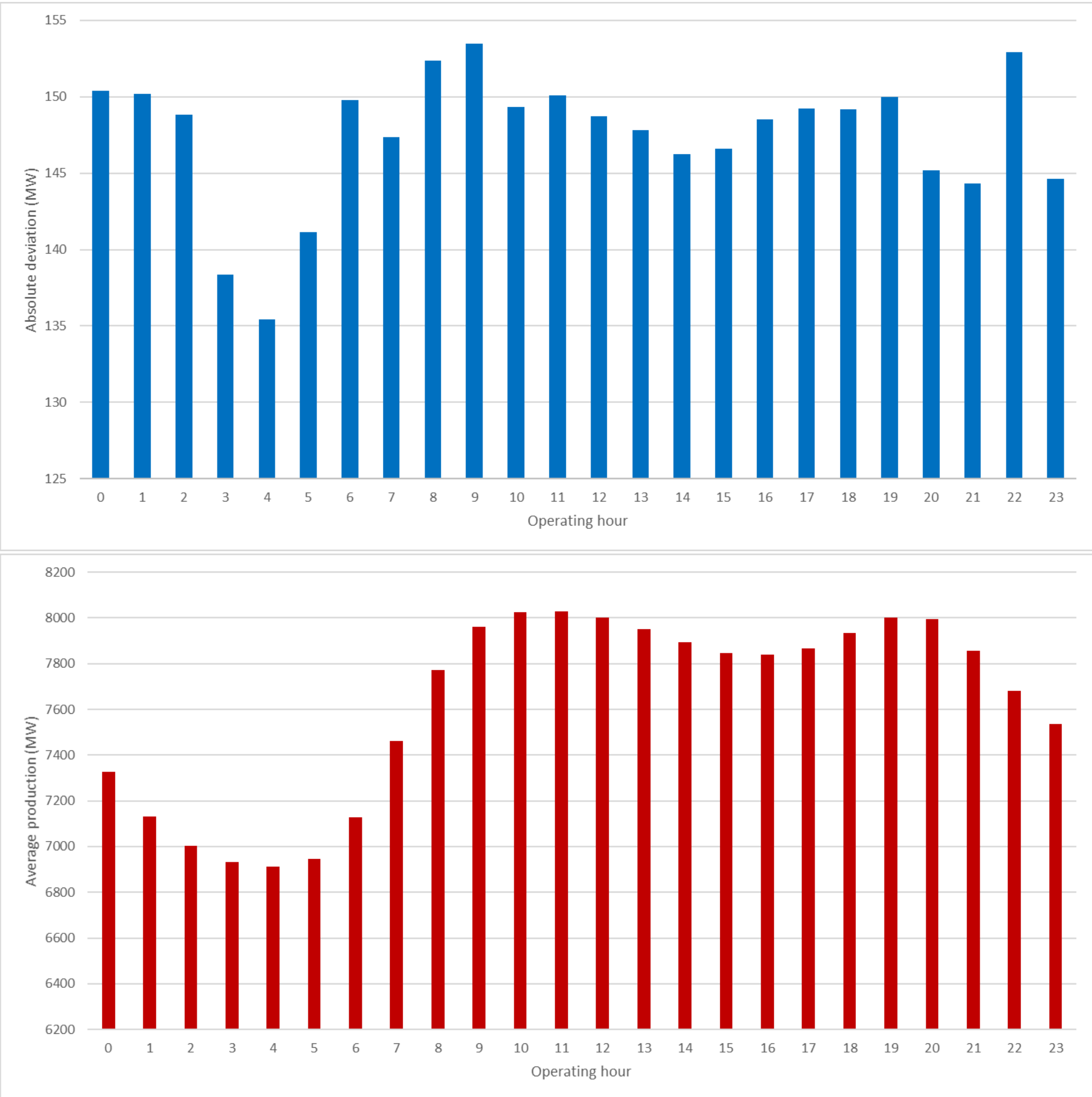


Figure 25: The upper graph represents average absolute deviations in MW between production plans and actual production per operating hour and the lower graph represents average electricity production power per operating hour in Finland between 2009 and 2018.

One intuitive observation is that the deviations seem to have followed the production pattern: During high production hours, the deviations have also been high and similarly, with lower production rates the deviations have tended to be lower. However, this is not the only factor explaining the magnitude of the deviations. It seems that every time the trend of the production has been either increasing or decreasing, the deviations have been higher than during the steady production periods. For instance, the average production has been relatively low at 06:00 compared to the afternoon hours. Nevertheless, the average deviation of the sixth operating hour is on the same level with the deviations of the afternoon hours. It is noteworthy that the sixth operating hour is the hour when the production has started to ramp up in the morning, which means that the state of the production has been changing. The same applies to the early hours: The production volumes have been comparatively low, but the deviations for the hours have been high. The production pattern shows that during the early hours the production has been declining on average. These findings indicate, that the periods of change are harder to predict on an accurate manner as the production plans tend to be less reliable.

It is good to acknowledge that there are also other factors influencing on the deviations between production plans and actual production that cannot be interpreted directly from the graphs in the figure above. For example, around the day shifts the changes related to the planned production can be high (ENTSO-E 2016). Thus, along with declining production, the actions around day shift can be a contributory cause for the high deviations in the early hours. Moreover, not all of the balance responsible parties observe electricity markets around the clock (Schariff & Amelin 2016). This fact signifies that the BRPs may not be extremely active during the night times and therefore, the production imbalances are not paid attention as much as during the midday operations. This, in turn, results in the deviations between production plans and actual production. In addition, one eye-catching case in the figure is the deviation peak taking place at 22:00. The reason for such a high average deviation might be the popularity of time-of-day electricity contracts in Finland. These contracts are based on day and nighttime division: Daytime is effective from 19:00 to 22:00, whereas nighttime is effective from 22:00 to 07:00 and has lower electricity unit charge (YLE 2016). Thus, the 22nd operating hour triggers higher electricity demand especially on cold winter nights, since it is cheaper for the household consumers to use electricity, for example, in order to heat up hot-water tanks. Such a sudden change in demand challenges production planning, which may possibly be the reason for high deviations between planned and actual production at 22:00. Overall, there is no unambiguous answer to explain when and why the deviations are the highest, which weakens the usability of production plans from the system imbalance prognosis point of view.

As mentioned earlier, there is an evidence that the imbalance settlement model have reformed the behavior of the balance responsible parties: From the year 2009 when the model was introduced onwards, the deviations between production plans and actual production have had a downward trend despite the increment in intermittent and weather-dependent production. To support this finding, figure 26 below shows the number of hours with positive and negative deviations between 2009 and 2018. In the recent years, the dominant direction of the deviations has been positive and the trend lines show that the number of hours with negative deviations is decreasing while the number of hours with positive deviations is increasing. Such a phenomenon can be explained by the incentives arising from the imbalance settlement model: Regardless of the imbalance pricing mechanism, the most beneficial strategy for the BRPs in order to minimize their settled imbalance costs is to aspire after small intentional surplus (van der Veen et al. 2012). It seems that the Finnish balance responsible parties have learnt from the experience how to reduce imbalance costs and thus, it is reasonable that the number of hours with positive deviations has increased. This reinforces the notion that market mechanisms and market based signals guides the operations of the BRPs and there is a strong linkage between production planning and incentives. The system level imbalance prognosis should take into account the fact that the balance responsible parties are interested in taking long positions.

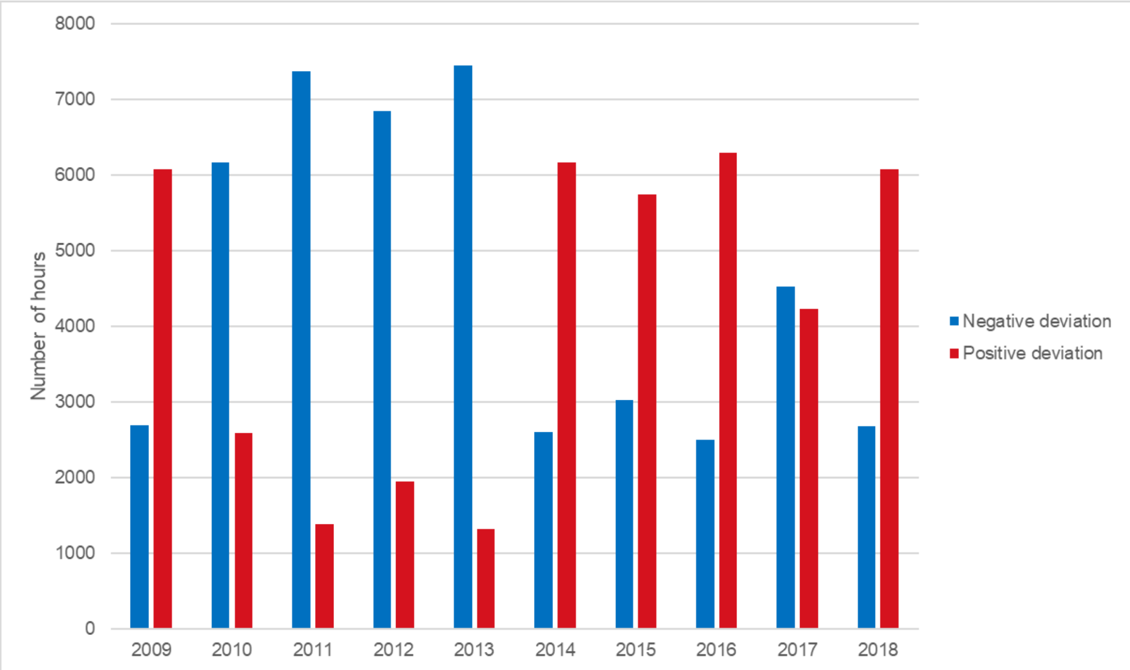


Figure 26: Number of hours with positive (red) and negative (blue) deviations between production plans and actual production per year in Finland between 2009 and 2018.

The findings above are central from the balancing philosophy point of view. TSOs that carry out proactive balancing rely on information that is available before the upcoming balancing period whereas reactive designs do not require that kind of extensive planning regarding the balancing. Production plans submitted by the balance responsible parties have been an essential part of the overview assessments that are made by the Nordic TSOs in order to prepare for the upcoming events. Such a procedure has been feasible due to the imbalance settlement model, which has motivated the BRPs not only to develop better production plans but also to behave according to the plans. This is demonstrated above by examining the key figures of the deviations between production plans and actual production. The trend lines show that the deviations has become smaller on average between 2009 and 2018, although the utilization of intermittent energy sources has increased simultaneously. From this point of view, it seems that the extensive planning could well remain as the core activity to determine the activation, direction and volume of the balancing products also in the future.

However, the upcoming market changes that are discussed more comprehensively in the previous chapters will bring plenty of uncertainty to the planning. First of all, the introduction of the new imbalance settlement model, which consists of single balance and single price, will change the incentives that guide the behaviour of the BRPs. Earlier it has been profitable for the balance responsible parties to minimize the deviations between actual production and production plans that they have submitted to Fingrid, which has ensured that the production plans have represented the upcoming production in a well-founded manner. The new model instead will give the BRPs more freedom to balance their positions not only with adjustable consumption but also with adjustable production. In addition, the model encourages the BRPs to take positions in to the right direction to support the system, which again can be done by adjusting production. Second, if the intraday market gate closure time is shortened close to zero permanently after the prospective pilot, it means that there will be electricity market trading taking place after the moment the balance responsible parties have sent the production plans to Fingrid. Thus, if Fingrid makes proactive decisions about the balancing several minutes before the start of an operating period based partly on the production plans, the outcome can be fundamentally flawed. Along with these points there are a few proven faults related to the production plans: When the state of production is changing, for example while the production is ramping up in the morning, the error margin of the production plans increase. Similarly, due to special occasions, such as day shifts, the deviations between production plans and actual production rise. All of these aspects question the relevance and usability of production plans and, by implication, the proactive design. So far the market approaches has guaranteed that the production plans are binding and the TSOs have had enough leeway and sufficient information to generate extensive assessments, but the market development is heading towards an environment, where the BRPs have better tools and more freedom, not to mention more responsibility, related to the balance management. Thus, it is somewhat conflicting if Fingrid will continue to make proactive decisions based on plans that are more like estimates. The BRPs will always have the best knowledge concerning their own behaviour and assets, which can be harnessed for imbalance mitigation by providing proper incentives and operational environment for the balance responsible parties. Then, Fingrid could only take care of the stochastic real time imbalances by performing reactive actions.

It is noteworthy that Fingrid uses production plans also for other purposes along with balance management. For example, the plans are a basis of electricity shortage forecasts and network condition predictions. Thus, the lack of decent information about production planning could threaten the system security. Producers and BRPs will most likely create production plans for their own use and for portfolio management despite the fact that the production plans will no longer be a part of the imbalance settlement in the future. This raises a question, if there is a need for an incentive to ensure that the BRPs are willing to submit reliable production plans to Fingrid in the future. For instance, such an incentive could penalize BRPs for deviations that are out of predefined limits. Another example is an incentive, which could penalize the BRPs that deviate from the production plans in the wrong direction, i.e. their deviations do not support the system. However, these incentive models are inconsistent with the introduction of single balance and single price model: Why to implement market solutions that promote certain market-based behaviour, which is restricted by some other mechanism at the same time? One potential solution is that Fingrid starts to create a production prognosis that is not based on the production plans of the BRPs. Currently, the consumption forecast is based on former metered data and other variables, such as weather conditions and there is no input from the BRPs. Similarly, Fingrid could forecast production, which could also support the installation of weather-dependent production: Probabilistic forecasting could possibly reduce the amount of reserve capacity that is needed to handle wind power forecast errors (Jung & Broadwater 2014). Overall, production forecasting and the different alternatives require further research.

4.3 Availability of frequency restoration reserves

Most often proactive balancing designs are associated with the utilization of manual frequency restoration reserves, whereas reactive balancing designs generally relate to the usage of automatic frequency restoration reserves. In the Nordic synchronous system, it is recognized that the volume of aFRR is limited (ENTSO-E 2016). Thus, it is reasonable to analyze the availability prospects of the reserves as they have more or less influence on the balancing philosophy.

Automatic frequency restoration reserve was introduced in the Nordic power system in 2013 and Fingrid ensures its availability by maintaining a capacity market, which enables Fingrid to procure aFRR for certain morning and evening hours (Fingrid 2019i). Thus, the automatic frequency restoration reserve type is quite immature and its utilization is limited in the Nordics. However, the upcoming changes will significantly affect the current situation. Firstly, as discussed in chapter 3, a new joint Nordic aFRR capacity market will be introduced along with an energy activation market. Secondly, the Nordic TSOs have agreed on an aFRR ramp-up plan, which aims to promote the aFRR availability and usage and make the aFRR procurement more cost efficient. The plan is based on two cornerstones: ramp-up of aFRR hours and capacity procurement volumes. They will be both increased gradually so that the aFRR can be utilized during all hours or quarters and the volumes will comply with the new dimensioning principles. (Affärverket Svenska kraftnät et al. 2018) These changes will provide the market participants with an indication, that the Nordic TSOs are increasingly interested in the utilization of automatic frequency restoration reserves. In addition, the changes and the ramp-up plan will improve the maturity of the aFRR market gradually. Thus, according to these aspects it is reasonable to assume that the availability of aFRR will increase in the future.

The new specifications for the automatic frequency restoration reserve product will also increase the availability of the aFRR resources. The current specifications for the bids are quite demanding: As mentioned in chapter 2, the minimum size on an aFRR bid is 5 MW and the full activation time is 2 minutes. The upcoming changes related to the automatic frequency restoration reserve markets will change the current situation dramatically. Simultaneously with the introduction of the new aFRR marketplaces, the specifications will be modified so that they will comply with the standard product specifications of the PICASSO platform. The minimum bid size will decrease down to 1 MW and the full activation time will increase to 5 minutes as stated in chapter 3. The reduction in the bid size and the increment in the full activation time will improve the availability of the automatic frequency restoration reserve resources, which can be explained with a couple of factors. Firstly, the longer FAT will increase the number of bids submitted by the balance service providers and as a result, enhance the liquidity of the markets for aFRR capacity and energy (ENTSO-E 2018d). This has been proven in the Netherlands, where the transmission system operator TenneT NL developed a slower aFRR product with a longer full activation time. Consequently, the market liquidity increased, because more resources were able to participate in the market due to the lower requirement, and additionally, the prices of the bids decreased. (van Wanrooij et al. 2014) Secondly, the loosen requirement for the bid size will allow slower and smaller resources to participate in the aFRR market. The following example supports this claim: Electricity production units differ in terms of ramping rates. For instance, for some thermal units the maximum loading rate can be around 2 % of the maximum continuous rating per minute whereas the same number can be 100 % for hydro units (Kundur 1994). Thus, the power output change of certain production resources is fairly limited. However, a thermal unit with the above ramping rate and a 10 MW output power can increase or decrease its production by 1 MW over 5 minutes period and therefore, it can participate in the automatic frequency restoration reserve markets. With the current bid size limit of 5 MW, that same thermal unit is not able to offer its flexibility to the aFRR market.

Compared to the automatic frequency restoration reserve, the manual FRR type is much more mature and its availability is better. There are a couple of reasons for that. First, as brought out in chapter 2, Fingrid maintains both capacity market and energy activation market for mFRR and the markets cover all hours of the day. Secondly, the current balancing philosophy exercised in the Nordics leans mainly on the utilization of manual frequency restoration reserves and thus, the demand has created supply. Figure 27 below shows the activation percentage of available mFRR bids with up and down balancing direction. The percentages are calculated by comparing the sum of bids in the balancing energy market and the volume of ordered bids from the balancing energy market in Finland in 2018. The data is retrieved from Fingrid’s open data website. The graphs show that the availability of mFRR bids including both balancing directions has been sufficient. For the up balancing direction, the highest activation percentage has been approximately 70.2 % and for the down balancing direction, the same number has been approximately 58.6 %. However, most of the time the activation percentages have been closer to zero. If all the hours with zero activation are left out, the average activation percentage for up balancing direction is approximately 6.4 % and the average activated volume is 53 MW. The same numbers for down balancing direction are 9.3 % and 52 MW, respectively.

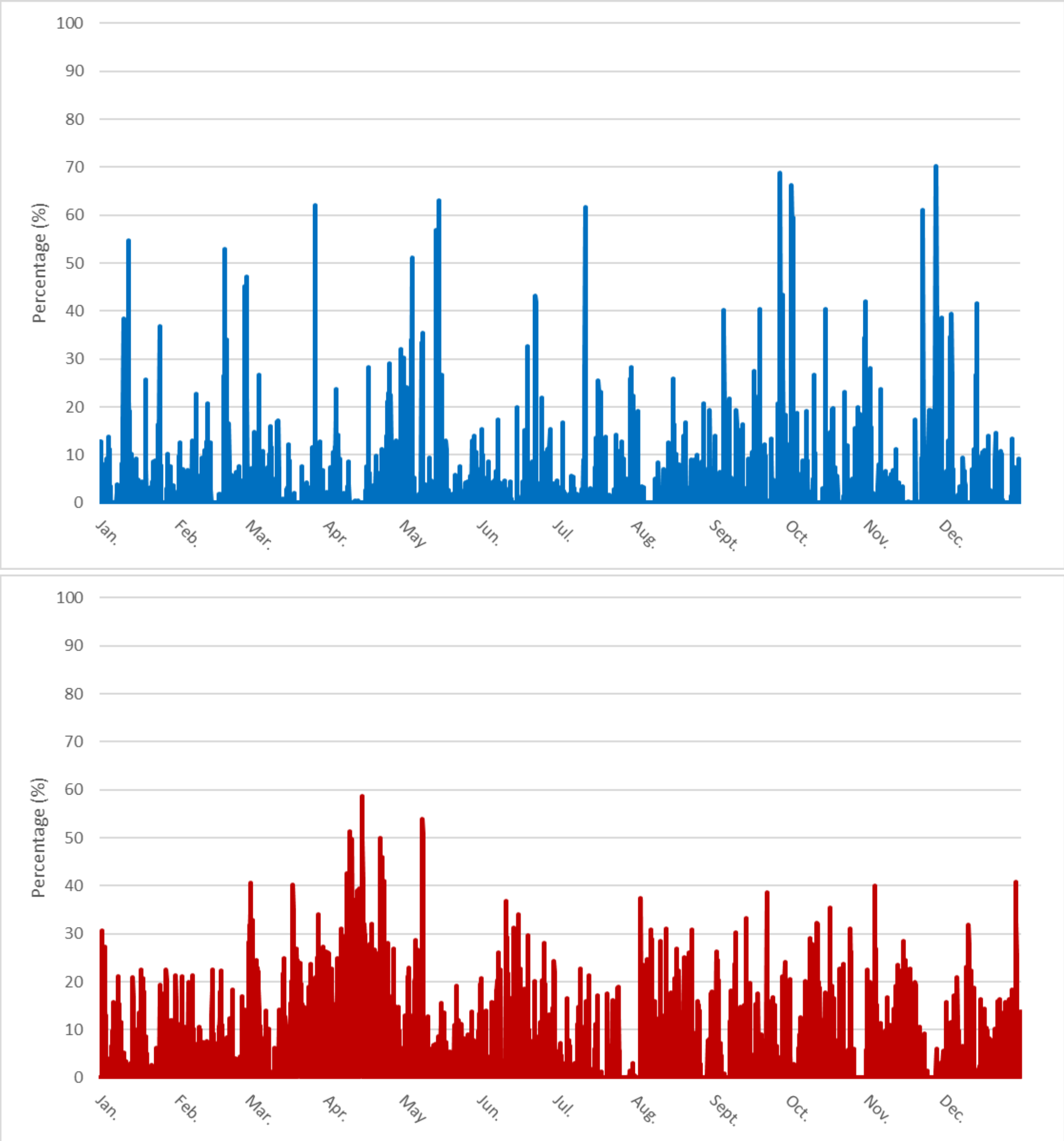


Figure 27: The upper graph represents the activation percentage of available mFRR up balancing bids and the lower graph represents the activation percentage of available mFRR down balancing bids in Finland in 2018.

The current availability of mFRR may change in the future because of the upcoming development steps. The product specifications of manual frequency restoration reserve will undergo modifications due to the MARI platform, which defines the standard mFRR product characteristics. As described in chapters 2 and 3, the mFRR specifications will change in the following way: The minimum bid size will decrease from 5 MW to 1 MW and the full activation time will decrease from 15 minutes to 12.5 minutes. As discussed above, the full activation time affects the ability of the reserve resources to participate in the markets. In this situation, the decreasing FAT will rule slower resources out of the mFRR markets. However, the decreasing minimum bid size will allow smaller resources to participate in the markets. Thus, it is hard to conclude what the overall impact of the specification modifications on the availability of manual frequency restoration reserve is.

Along with these findings related to automatic and manual FRR, it is worth investigating if there exists a correlation between the day-ahead price and the availability of reserve resources. Since there is energy activation market only for the manual products, the analysis is based on the sum of mFRR bids in the balancing energy market and the day-ahead prices in 2018. The datasets are retrieved from Fingrid's open data and Nord Pool's market data websites. Figure 28 below shows the correlation for both balancing directions.

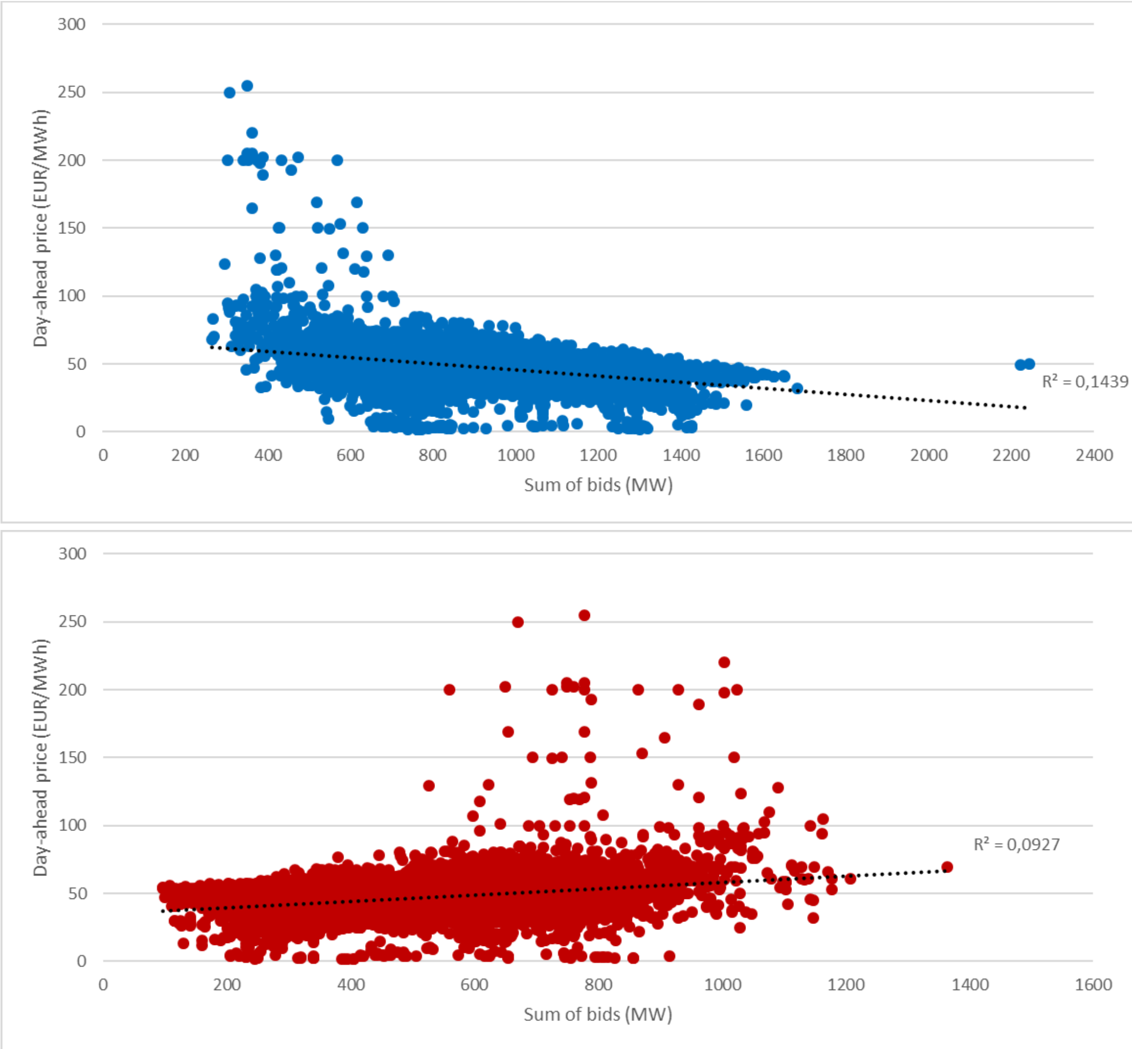


Figure 28: The upper graph represents the correlation between day-ahead price and sum of mFRR up balancing bids and the lower graph represent the correlation between day-ahead price and sum of mFRR down balancing bids in Finland in 2018.

The above graphs and especially the trend lines show that there really exists a slight correlation between the day-ahead prices and the availability of manual frequency restoration reserve bids. The r-squared value, which measures how well the regression trend line reflects the real data points, is 0.14 for the up balancing direction and 0.09 for the down balancing direction. Therefore, the correlation is stronger between the day-ahead prices and the up balancing bids than between the day-ahead prices and the down balancing bids. According to the analysis, the sum of mFRR bids with up balancing direction increases when the day-ahead price decreases and for the bids with down balancing direction, the trend is the other way around. It is also interesting how the sum of bids behaves during price spikes. The sum of up balancing direction bids tends to be low during the day-ahead price spikes and the sum of down balancing direction bids tends to be high during the day-ahead price spikes.

Based on the above speculation, it is reasonable to consider the outlook for the day-ahead prices in order to analyze the availability of reserve resources in the future. According to Spodniak et al. (2019), the overall price levels on electricity wholesale markets are decreasing in the Nordics because of the increasing share of production methods with low marginal costs, such as wind and solar power. In addition, the increment in the capacity of wind and solar power increases the electricity price volatility meaning that price spikes will take place more frequently. Considering these facts, it is impossible to conclude the overall influence of the day-ahead price on the availability of the reserve resources in the future. The decreasing price level will possibly increase the sum of up balancing bids and decrease the sum of down balancing bids in a slight manner. On the other hand, the increasing number of price spikes will lower the sum of up balancing bids and boost the sum of down balancing bids. In addition, it is hard to say if these findings apply to aFRR energy activation bids, as there is no such data available.

All in all, in the current situation it is safe to say that the availability of mFRR is superior to the availability of aFRR. Firstly, the current balancing philosophy relies strongly on the manual FRR type and the resulting demand has created sufficient supply. In addition, the marketplaces for mFRR are mature and cover all hours of the day. Taking into account these findings and the assumption that mFRR is typically a cornerstone of proactive designs, Fingrid should definitely exercise proactive balancing also in the future. However, the outlook for the availability of aFRR is promising. The upcoming marketplaces will promote the availability of automatic frequency restoration reserve along with the relaxation of the bid requirements and specifications. In addition, it must be noted that the upcoming market solutions discussed in chapter 4.1 will theoretically reduce the demand for balancing product activations due to occurring imbalances are smaller and therefore, the availability of reserves will be less restrictive principle in the future. Based on these findings and the assumption that reactive designs rely mainly on aFRR, Fingrid can start moving towards a balancing design that is more reactive. In addition, mFRR bids can be activated reactively, if the activation type of the bid is direct activation. Thus, the mFRR bids can be utilized reactively to release already activated aFRR, which ensures the aFRR availability when new imbalances occur.

4.4 Economic optimization

Most often, the processes of different companies are carried out in a way that enable the companies to achieve high – or at least sufficient – quality at the lowest possible cost. This is called as the economic optimization of process design and it is a valid aspect to take into account when determining the balancing design of the Finnish power system.

Economic optimization related to balancing can be considered from both short-term and long-term point of view.

Short-term economic optimization relate to the utilization of manual and automatic FRR products: There may appear price differences between the two, which could lead to changes in how the products are utilized in order to optimize direct balancing costs. Equation 4 below represents a total cost function of a TSO for the balancing product utilization taking into account energy payments. Capacity payments are sunk costs that cannot be recovered and thus, they are not involved in the equation. It should be noted that the payments related to down balancing reduce the total costs, because Fingrid charges the selected down-bidders for the energy according to the determined balancing energy price. On the other hand, up balancing increases the total costs as Fingrid compensates the selected bidders for the energy according to the determined balancing energy price.

$$C_{total} = C_{mFRR-up} - C_{mFRR-down} + C_{aFRR-up} - C_{aFRR-down} \tag{4}$$

Where,

$C_{mFRR-up}$ = Cost of mFRR up balancing

$C_{mFRR-down}$ = Cost of mFRR down balancing

$C_{aFRR-up}$ = Cost of aFRR up balancing

$C_{aFRR-down}$ = Cost of aFRR down balancing

Proactive balancing designs are based on the utilization of manual frequency restoration reserve type. From cost optimization perspective, the proactive balancing actions are profitable in situations, where the supposed costs related to the mFRR-based balancing are lower than the costs of reactive aFRR-based balancing. In the current situation and in the near future when the aFRR energy market is launched this may hold true, because the energy market for mFRR is mature and the availability of mFRR resources is better than that of aFRR. However, this kind of cost optimization as a whole is infeasible due to several reasons. First, the aFRR energy market will not quickly evolve further, if Fingrid promotes proactive design and the usage of manual FRR because of the lower prices. Secondly, if Fingrid aims to minimize its own costs related to the balancing, the outcome can be technically and economically inefficient due to the counter activation of balancing products (van Wanrooij et al. 2014). Along with these reasons, the proactive decision about the scheduled activation of mFRR needs to be made well before the actual operating period. Thus, the determination of the mFRR demand is based on the imbalance prognosis, which includes inaccuracies as discussed earlier in this paper. Figure 29 below presents how the actual imbalance may differ from the imbalance prognosis, which reflects only the average imbalance over the period. This results in uncertainties, which truly challenge the proactive cost optimization, since there is no existing way to accurately forecast the balancing energy prices that are determined during the period of operation.

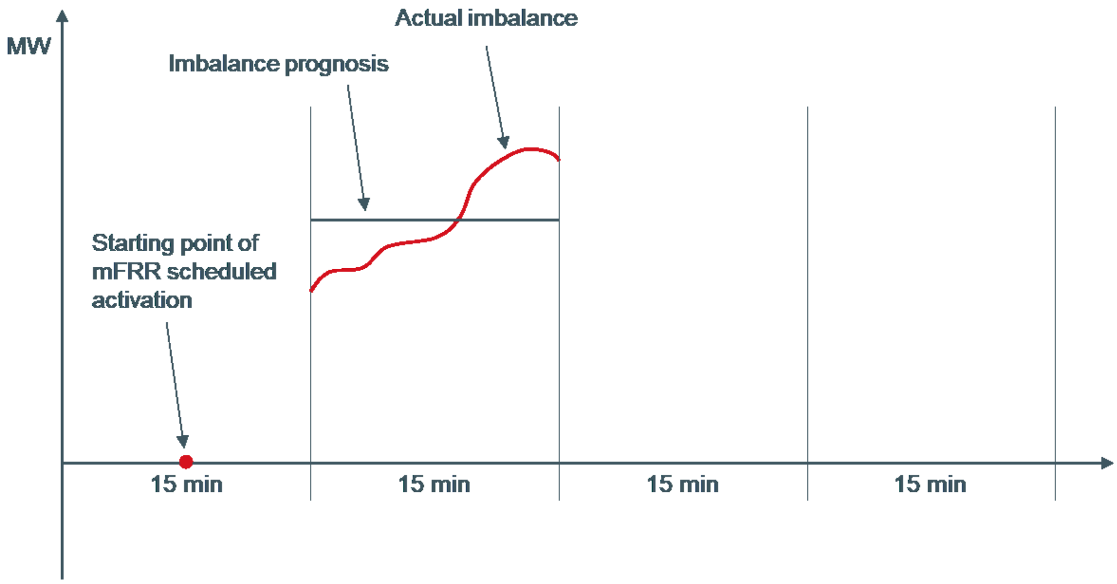


Figure 29: Illustrative example of a hypothetical situation in which the imbalance prognosis (black line) differs from the actual imbalance (red line) during the balancing period.

Long-term economic optimization is interested in the economic benefits that arise over longer period of time. As brought out in chapter 4.1.3, the amount of activated balancing energy and the procurement volumes of frequency restoration reserves in Germany have decreased after giving the balance responsible parties better tools and more responsibility related to the proactive balancing. The same findings can be observed in Belgium: According to van Wanrooij et al. (2014) the absolute imbalance volumes have decreased and the ACE quality has improved after the introduction of more reactive balancing design. These two are good examples of how the reactive designs entail plenty of benefits – also from the economic point of view. Decreased amount of activated balancing energy results in lower balancing costs and reduced volume of imbalances means lower imbalance costs for the BRPs.

Overall, the economic optimization is a hard task including plenty of uncertainties. The proactive short-term optimization may lead to unfavorable situations whereas the long-term optimization promotes designs that are more reactive at least according to a few European examples. Due to the findings, Fingrid should exercise reactive balancing design in the future in order to support long-term economic welfare.

5 Conclusions and discussion

This thesis studies the balancing philosophy of the Finnish power system by evaluating proactive and reactive balancing design choices from several perspectives including market solutions, usability of production plans, availability of frequency restoration reserves and economic optimization. The thesis shows that currently the Nordic TSOs focus on proactive balancing, which is based on different forecasts and expectations. The extensive planning determines the volume and direction of the manual frequency restoration reserve that is needed to be activated in advance of the period of operation. However, the Nordic power system balancing is undergoing major changes as the thesis has pointed out: The responsibility of each Nordic TSO related to the balancing of own control areas will increase and the utilization of market-based solutions along with stronger price signals will improve. Thus, the purpose of the thesis is to answer the questions: *"What are the implications of the upcoming changes for the balancing design of the Finnish power system?"*, *"Should Fingrid promote proactive or reactive balancing design?"* and *"What are the reasons for the design choice and what are the aspects that require further research?"*

Based on the findings of the thesis, Fingrid should promote reactive balancing design, which is justified by the following arguments. First, the upcoming market solutions that are single price and single position imbalance settlement model, 15 minutes imbalance settlement period and intraday market development all imply that the balance responsible parties will have better tools closer to real time and stronger incentives to maintain their own balance in the future. The balance responsible parties are encouraged to be more active and more conscious about their imbalances and portfolio management as the markets and underlying profits enable new possibilities while the balancing cycle shortens. This means that the market participants will most likely take care of the proactive balancing and forecasted imbalances in a more efficient manner and therefore, proactive balancing carried out by Fingrid would possibly lead to counter activations and unwanted balancing performance due to technical and economic inefficiency.

Second, Fingrid's imbalance prognosis model, which will rest on the production plans of the balance responsible parties, will lose ground, because the market solutions do not direct the market participants to comply with the production plans to the best of their ability. So far, the absolute deviations between production plans and actual production have reduced, but the upcoming imbalance settlement model will ignore the production plans, which challenges their quality and correctness. Thus, the prognosis model can be unreliable and if the proactive decision-making concerning the balancing product utilization is founded on it, the outcome can be flawed and the decisions can be false. In addition, the market participants have the best knowledge about their imbalances and portfolio, and thus, by letting them to take care of the balancing close to real time, the overall result can be more accurate and efficient.

Third, according to the facts presented in this thesis, the need for frequency restoration reserve activations and procurement is likely to decline due to the reduction of the imbalances in the system once reactive balancing design is introduced. When TSOs focus on reactive balancing, the balance responsible parties can make better use of their own flexibility and the electricity markets closer to real time in order to balance themselves and support the system with imbalance mitigation. This is likely to improve the efficient utilization of assets and decrease the costs related to the balancing, which results in overall economic welfare.

Fourth, the assertion that the Nordic TSOs need to rely on the utilization of mFRR due to the limited availability of aFRR in the Nordics is inadequately justified. If Fingrid starts to promote the reactive balancing design, which is founded on the utilization of the automatic frequency restoration reserves, the increasing demand will signify that the TSO is willing to take advantage of the available aFRR resources, which in turn will presumably create supply. In addition, the specifications of the aFRR bids will loosen, which is likely to improve the aFRR availability at least in theory. Along with these viewpoints, if the activation volumes decrease due to exercising reactive design, the availability is not that central restriction in the future.

It is evident that Fingrid should promote reactive design, since the benefits are considerable. To fully harness the potential of reactive balancing, this thesis recommends that Fingrid should start to publish balancing volumes, directions and prices as close to real time as possible. This would support the balance responsible parties with balancing. In addition, the intraday market development is very central and thus, the gate closure time of 0 minutes should be implemented on a permanent basis after the pilot. Along with the gate closure time, this thesis recommends that the intraday auctions are put into operation or at least investigated more precisely.

After all, the exact behavior of the balance responsible parties and the real consequences of the upcoming changes are hard to foresee. In addition, there are so many changes proceeding simultaneously and rapidly, which makes it impossible to take into account all the details and to anticipate all the possible outcomes. There are no available data regarding the markets and imbalances of the future and thus, this thesis has leant on the existing data and several assumptions meaning that the findings are based on the best current knowledge. In addition, a few aspects require further research. First, congestion management and network conditions have not gained much attention in this paper. It can be possible that the reactive balancing actions are not sufficient to handle power grid congestions, which is why there may exist a need for proactive TSO balancing in order to take care of the bottlenecks. Thus, the congestion management point of view should be discussed thoroughly. Related to this point of view, it should be also investigated further how Fingrid could secure the reliability and accuracy of production forecasting in the future.

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Appendices

Appendix 1. Deviations between planned production and actual production. 10 pages.

Appendix 1. Deviations between planned production and actual production

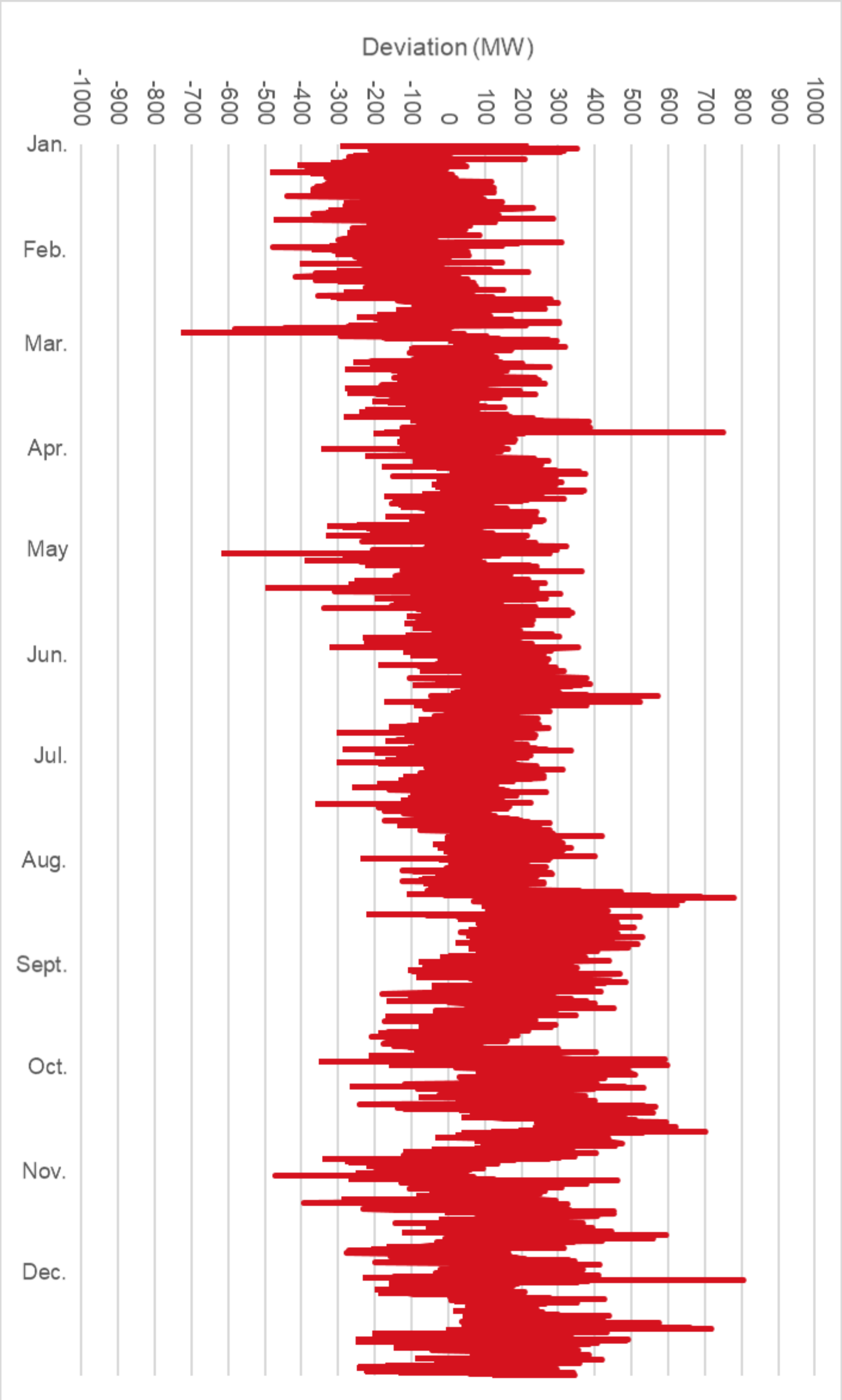

Figure 1. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2009.

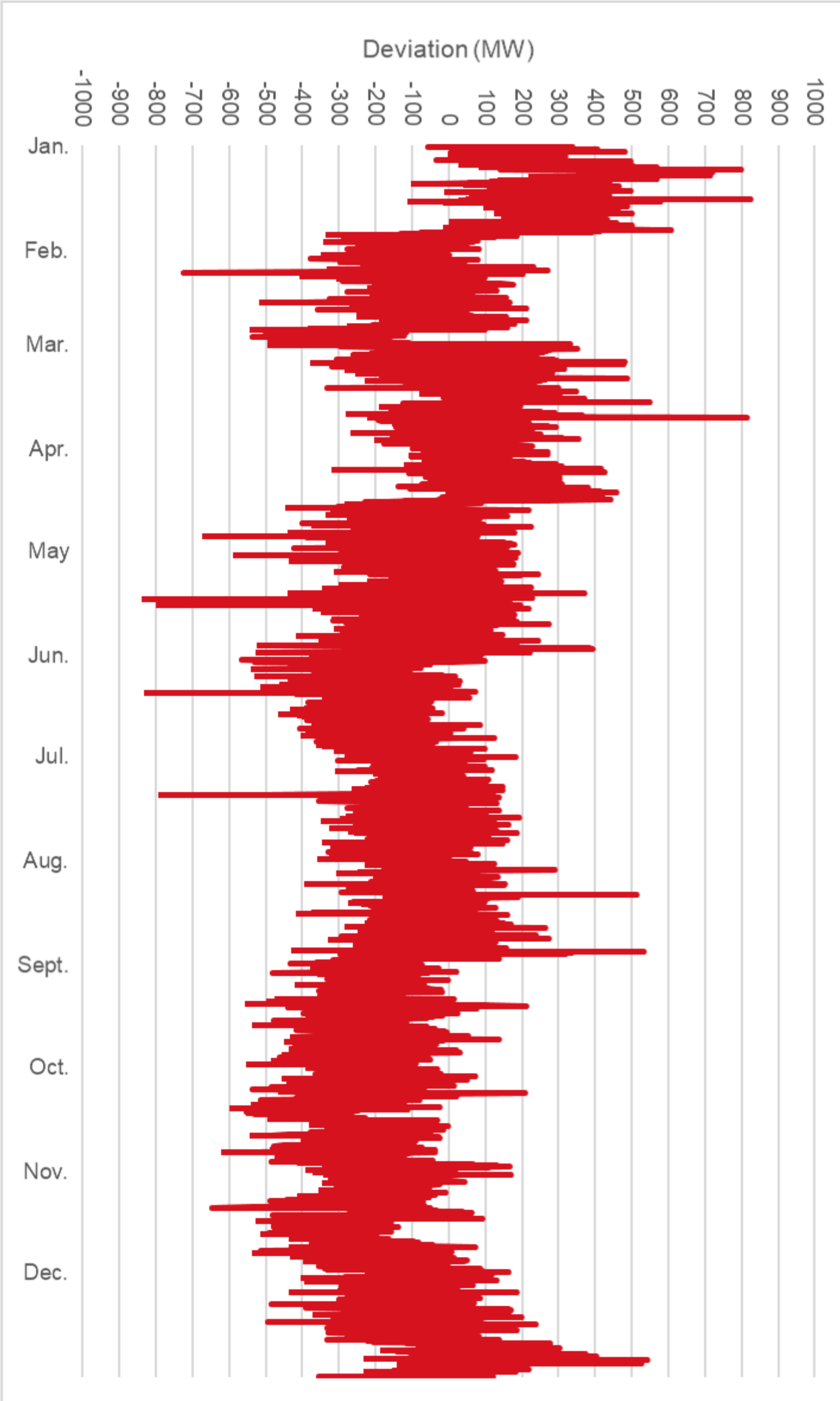

Figure 2. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2010.

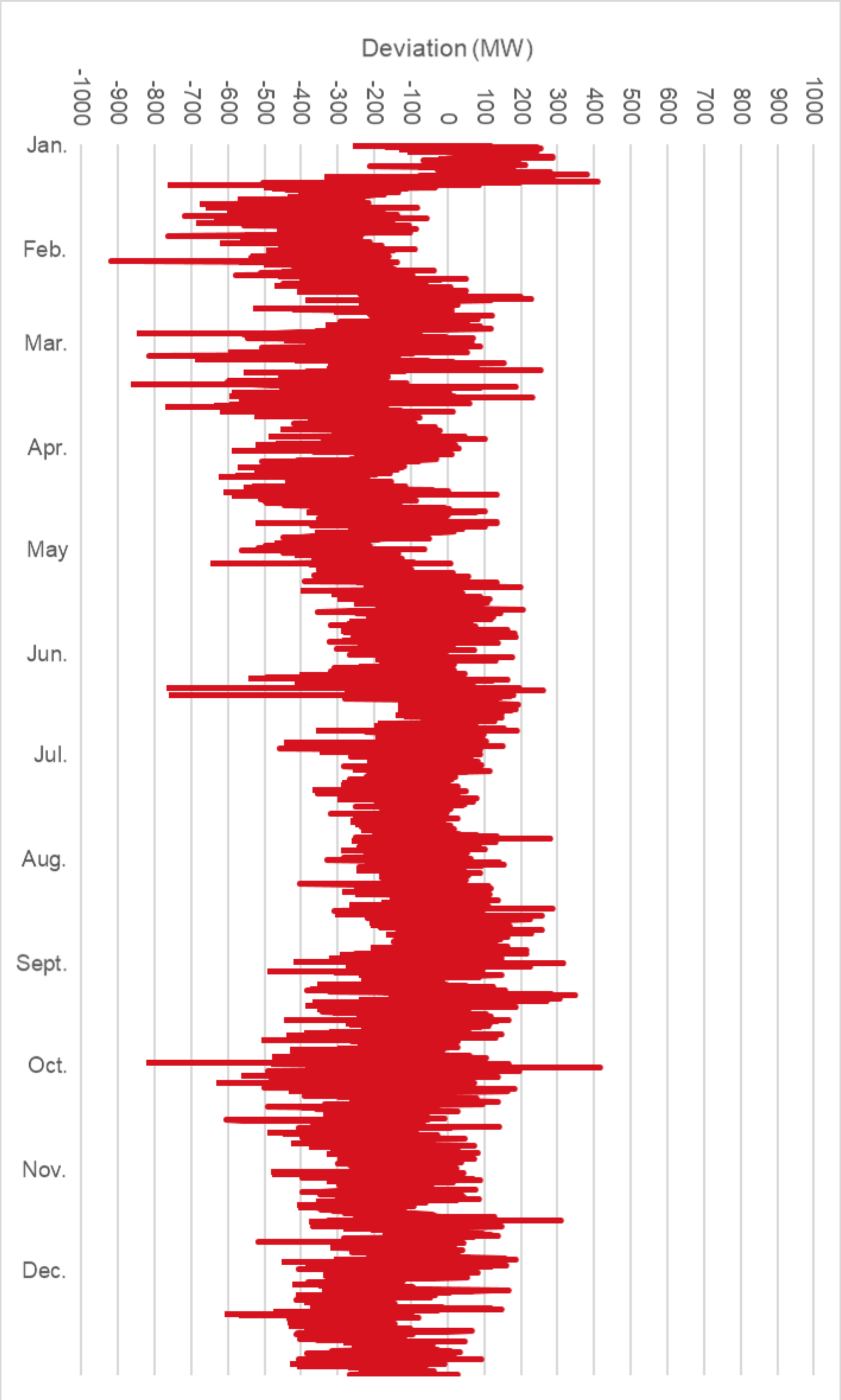

Figure 3. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2011.

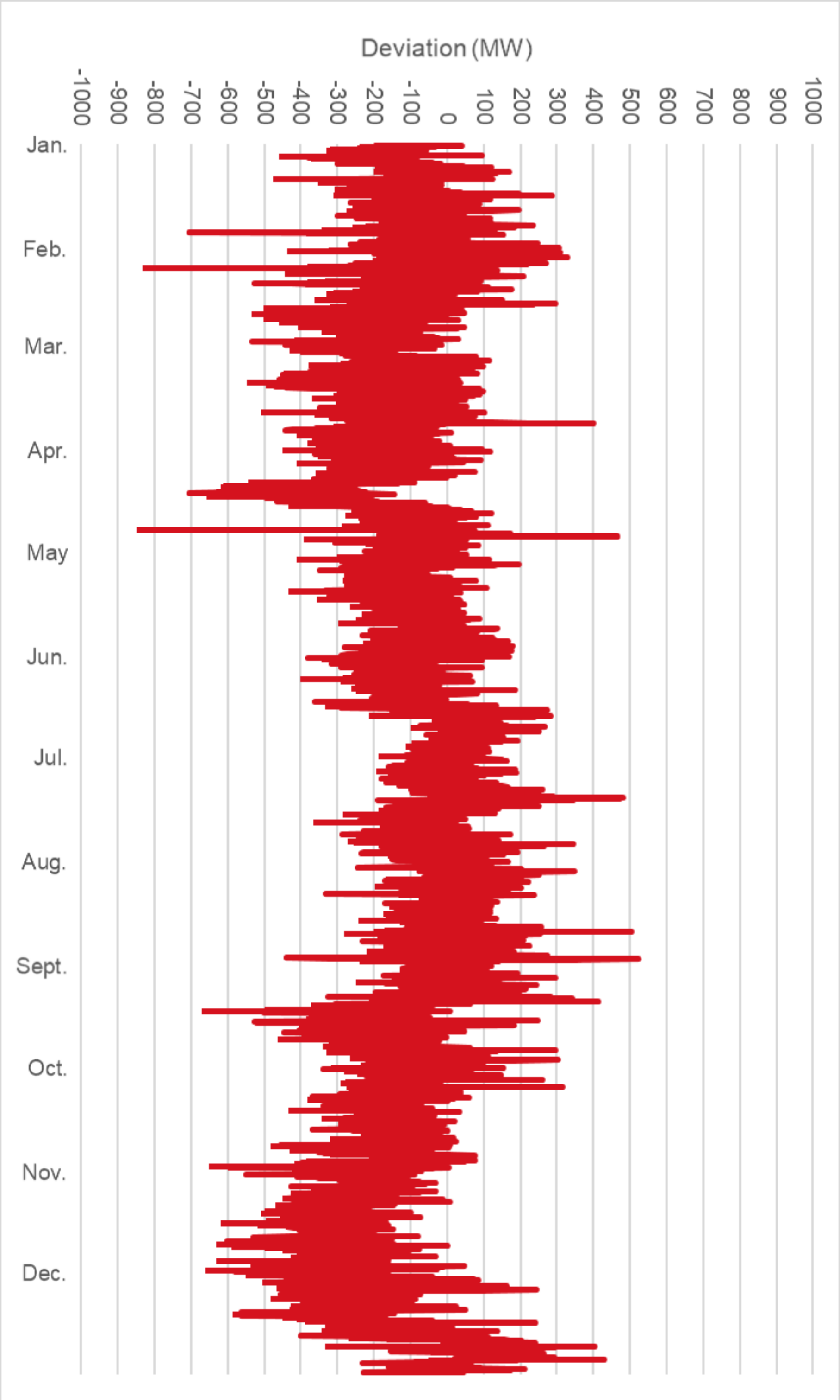

Figure 4. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2012.

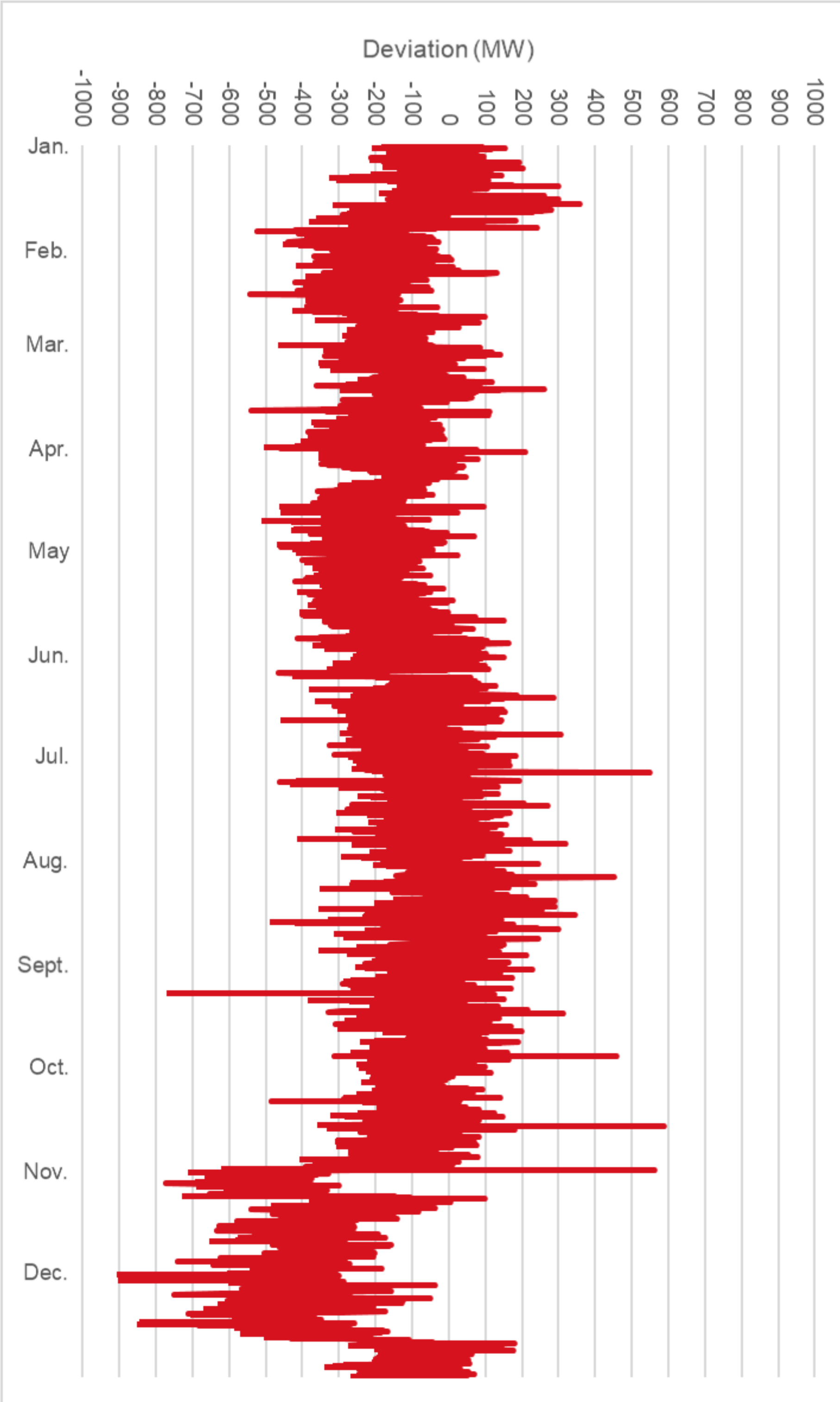

Figure 5. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2013.

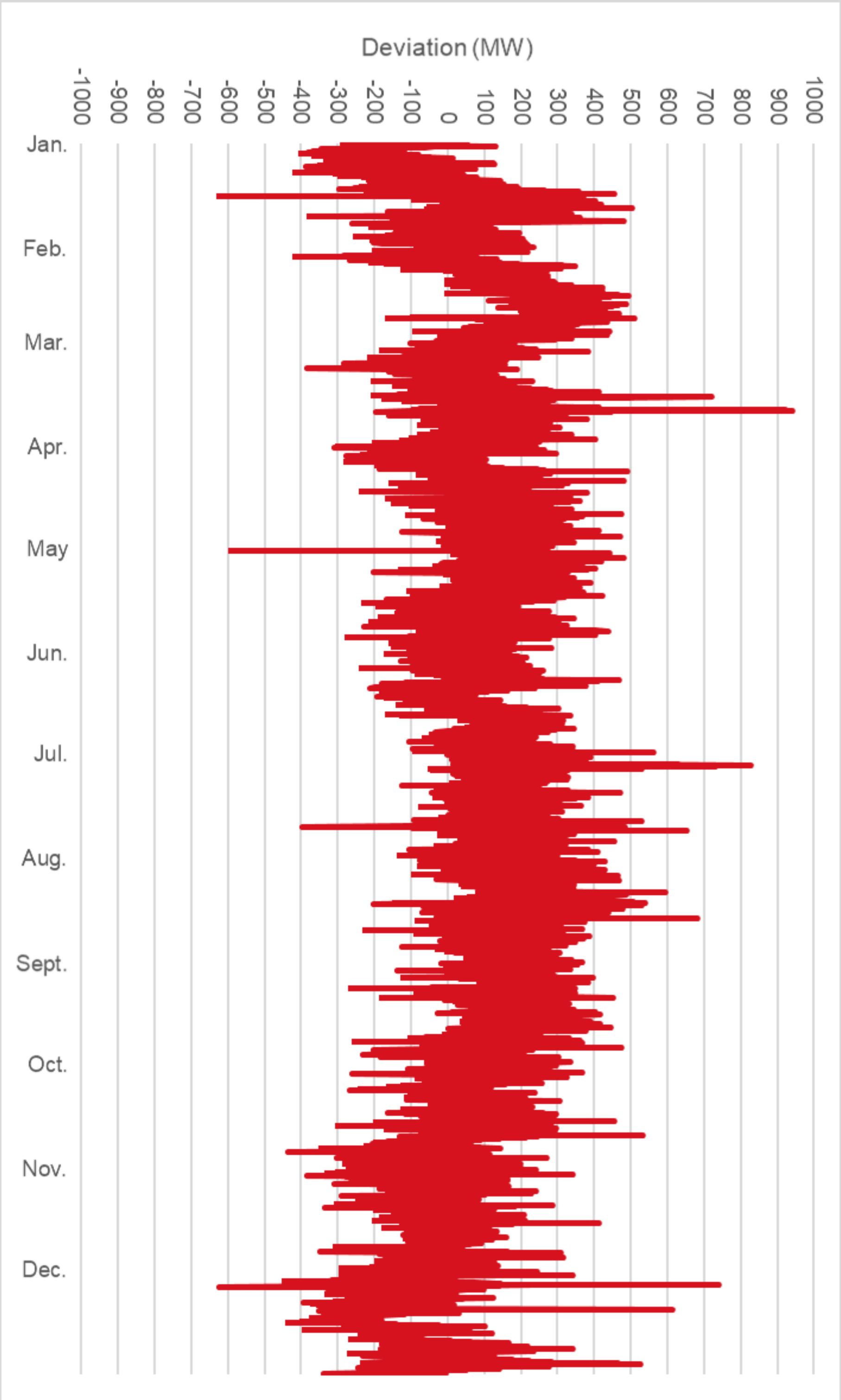

Figure 6. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2014.

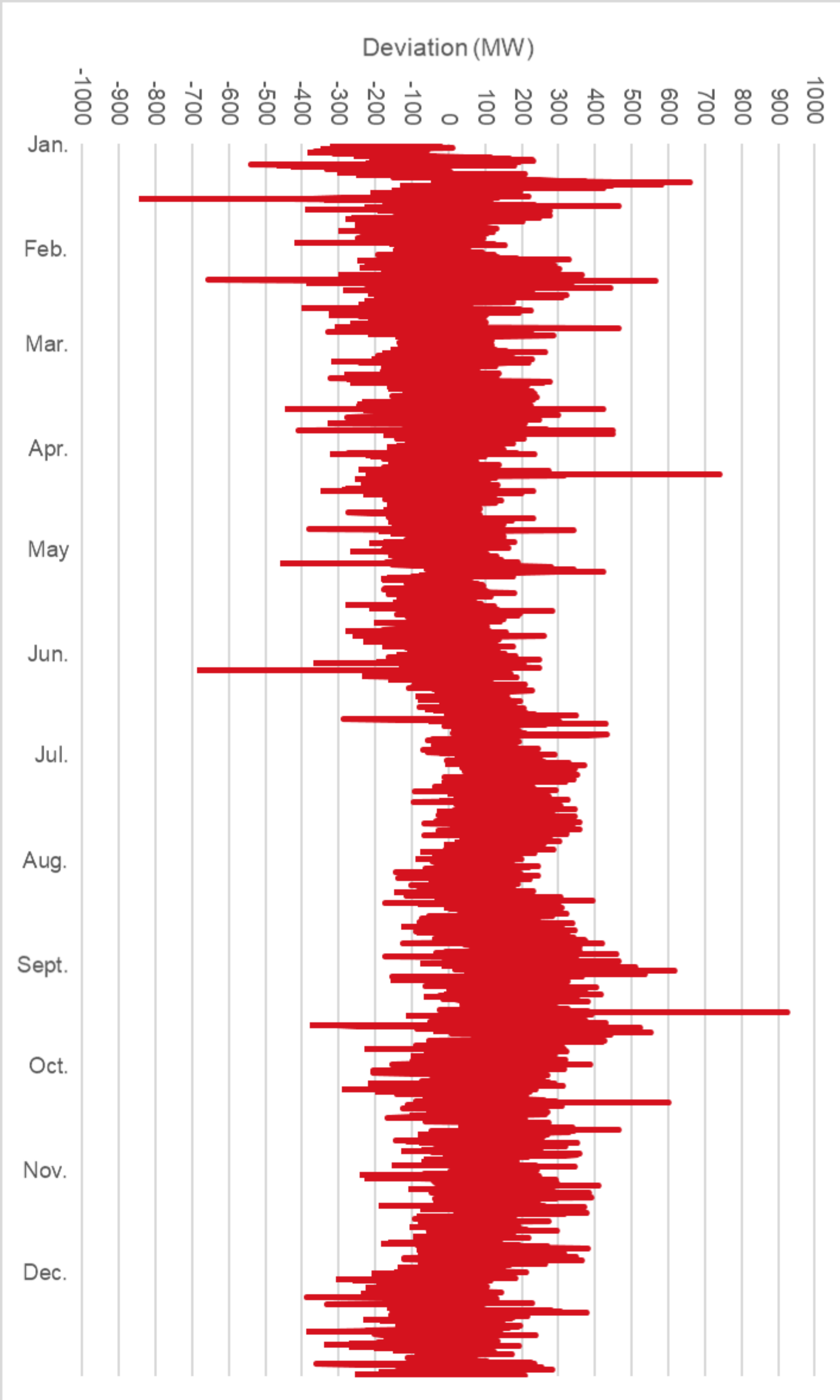

Figure 7. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2015.

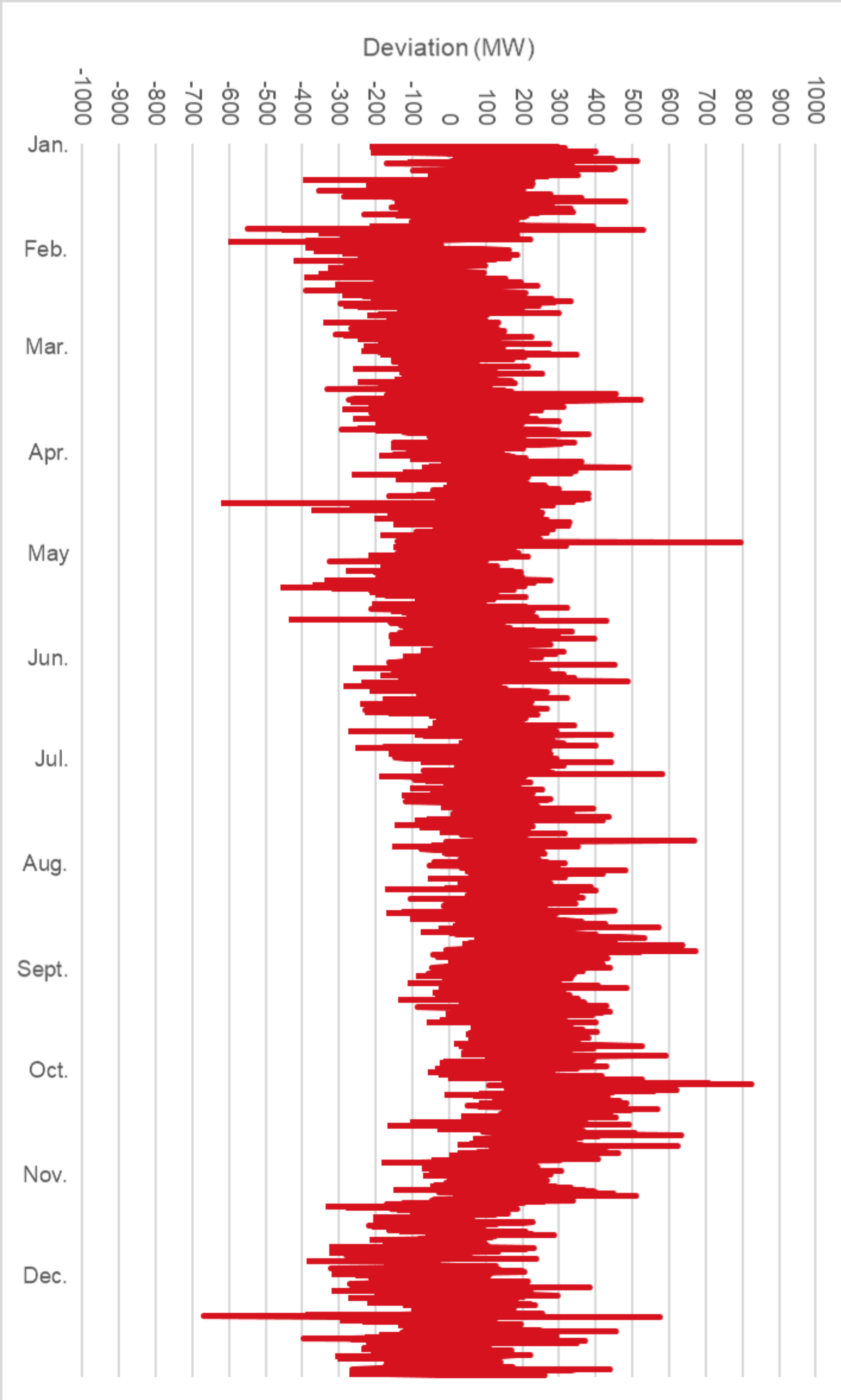

Figure 8. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2016.

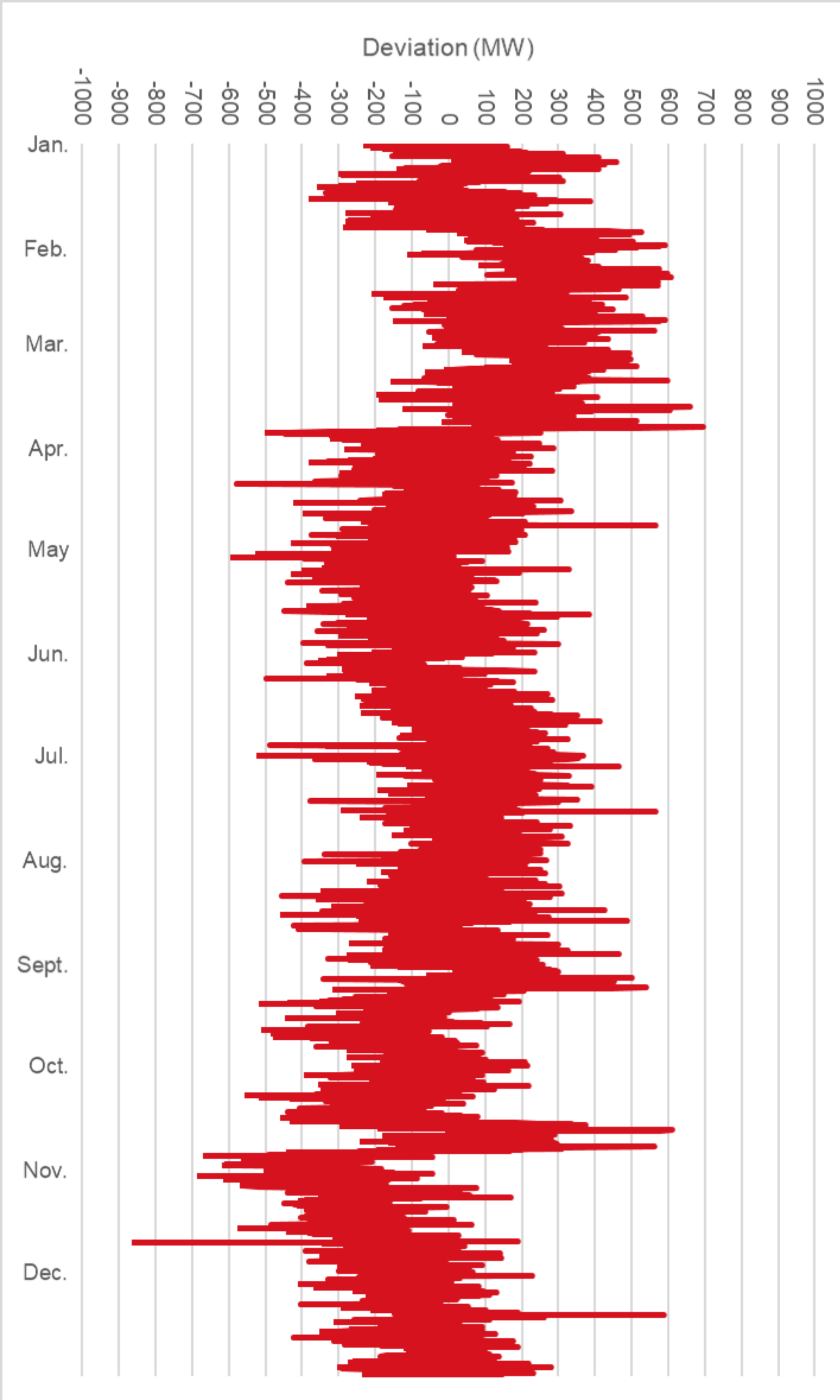

Figure 9. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2017.

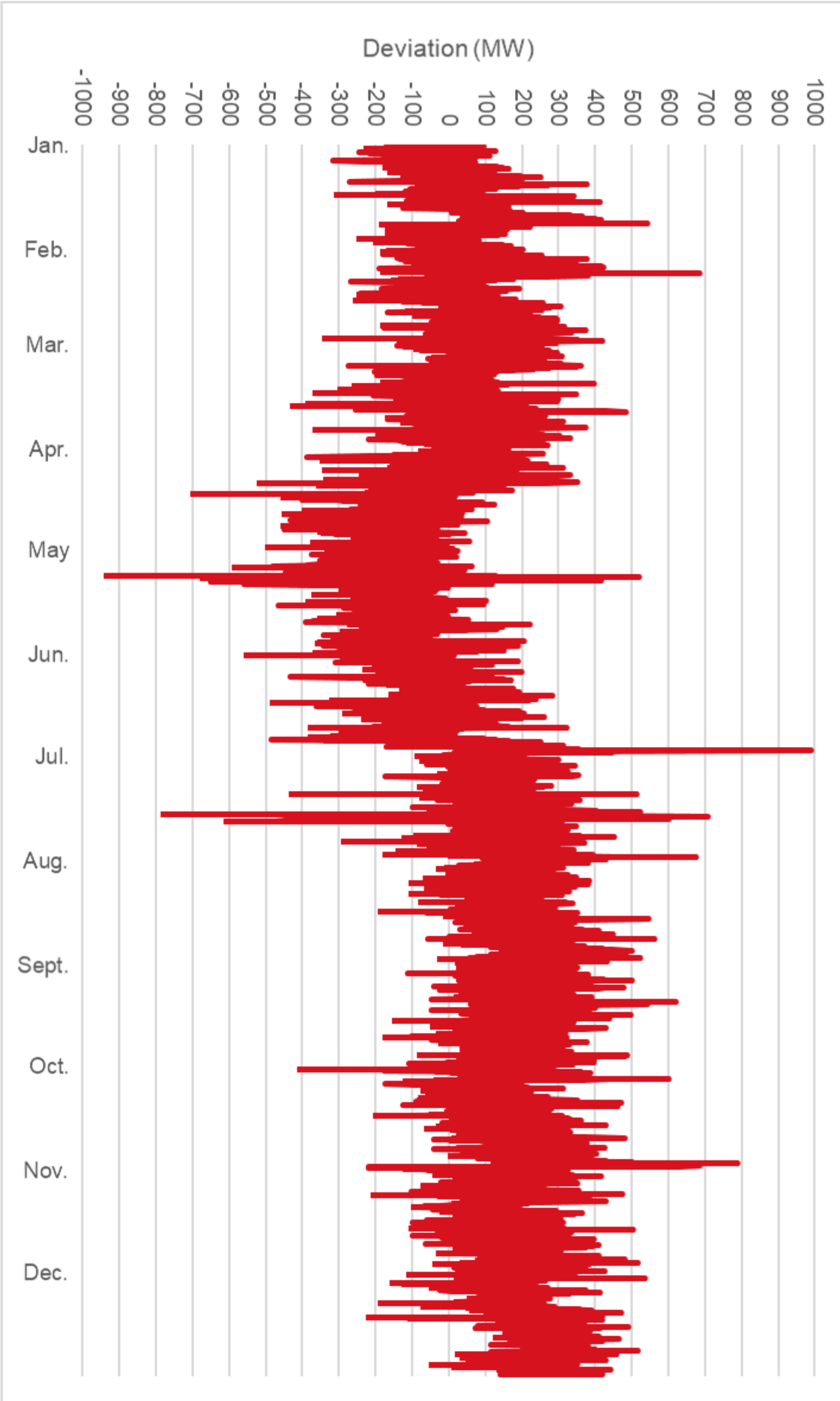

Figure 10. / Appendix 1. Deviations between planned production and actual production in MW in Finland in 2018.