INTRA-HOUR POWER BALANCE IN FINLAND IN 2020 AND 2030

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ABSTRACT

This paper is a summary of a master thesis in Finnish language which studied intra-hour power balance in Finland at the beginning and at the end of the 2020s. The thesis analysed what kind of challenges will occur in the intra-hour power system operation when large-scale renewable electricity production is integrated and the share of nuclear power increases in the Finnish power system and neighbouring areas. The thesis also answered to question how to cope with the future challenges.

1 INTRODUCTION

A balance between electricity consumption and production is needed constantly in the power system. Transmission system operator (TSO), in Finland Fingrid, is responsible for the intra-hour balance in the power system. TSO utilises automatic and manual reserves to maintain the balance between production and consumption.

The thesis concentrated on manually activated balancing power from the Nordic regulating power market. Chosen research method was case study. The idea was to define possibly needed regulation and market-based regulating resources available in example market situations in 2020s, and to calculate if the resources cover the need, i.e. whether there is a deficit between them.

General assumptions on the basis of market situations are discussed in Chapter 2. Need of balance regulation is analysed in Chapter 3. Cases are shortly described in Chapter 4. Finally, the results of the cases and conclusions are presented in Chapter 5.

2 DEVELOPMENT OF ELECTRICITY MARKET

Finnish yearly electricity consumption was between 84 and 87 TWh in 2010 - 2012 (Finnish Energy Industries 2013). According to the latest update of the Finland's Energy and Climate Strategy, electricity consumption will increase 10 % by 2020 and 20 % by 2030 (Ministry of Employment and the Economy 2013). Only 15 % increase by 2030 was used in the case study. Despite used yearly demand levels, lower and higher daily and hourly demand values will appear as today. Yearly demand levels affect mostly on the probability how often certain demand values appear.

Based on the European Union's climate policy and national goals, the share of renewable energy will increase remarkably in the Nordic countries and in the Baltic area. In this thesis, it was assumed that wind power production will be large-scale by 2020 and photovoltaic solar power production by 2030. Assumptions concerning development of the Finnish generation capacity are shown in Table 1.

Table 1 Generation capacity today, and assumed capacity in 2020 and 2030 (Source of the 2013 values: Finnish Energy Market Authority 2013).

	Generation capacity [MW]		
	2013	2020	2030
Hydro power	3000	3100	3200
Nuclear power	2750	4350	5000
Condensing power	3240	at least 1500	?
CHP, industry	2820	quite the same	quite the same
CHP, district heat	4480	quite the same	quite the same
Wind power	250	2500	4000
Solar power	not remarkable	not remarkable	1500

Assumed Finnish cross-border transmission capacity in 2020 and 2030 is presented in Figure 1.

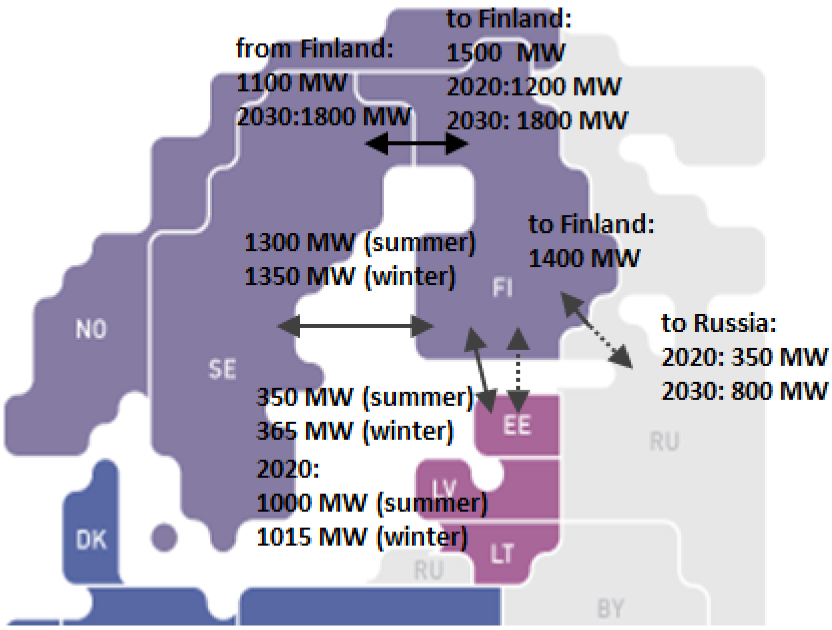

Figure 1 Cross-border transmission capacity in Finland today and assumptions for 2020 and 2030 (Modified from the data sources: ENTSO-E 2012a and ENTSO-E 2012b, p. 49).

Even though cross-border transmission capacity increases, as can be seen in Figure 1, fully loaded situations become more common because transmission flows will increase after wind and solar power integration. In addition, European electricity market integration and two-way trade between Finland and Russia may increase cross-border transmission flows.

3 NEED FOR BALANCE REGULATION

Balance regulation is needed to adjust the difference between real time consumption, i.e. load, and production. Both consumption and production vary from the hourly average value in an hour. In addition, there is often hourly imbalance between consumption and production because of forecast errors. Up-regulation is needed when load is higher than production, and respectively down-regulation is needed when load is lower than production.

Different factors, for example wind power changes and load changes, cause imbalance. For now, load variability has been more significant but production variability will increase after wind power and solar power integration. Need for balance regulation is at largest when there are imbalances caused by different factors at the same time and in the same direction. This possibly needed regulation was analysed in the thesis. It was formed by summing imbalances caused by different factors. Possibly needed up- and down-regulation are presented in Figure 2.

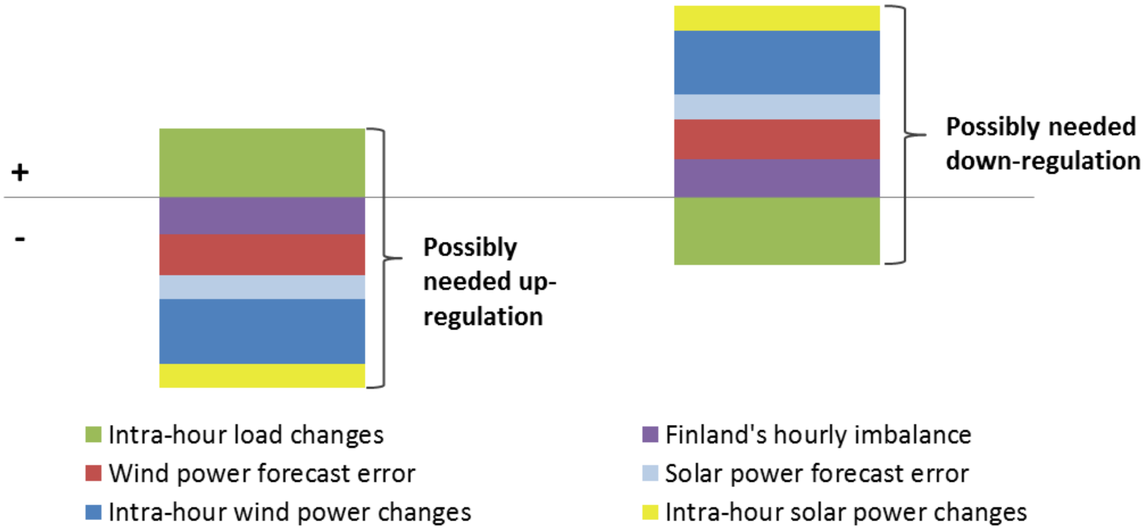

Figure 2 Possibly needed up- and down regulation.

As can be seen in Figure 2, up-regulation is needed if load increases and/or production decreases within an hour and/or hourly consumption is higher than production. Respectively, down-regulation is needed if load decreases and/or production increases within an hour and/or hourly consumption is lower than production. The thesis analysed regulation needs in normal operational state. In addition, wind power extreme situations were considered. Wind and solar power were evaluated as large-scale production.

3.1 Finland's hourly imbalance

Finland's hourly imbalance is the difference between hourly production and consumption in the whole of Finland. The statistics available at Fingrid's webpage were used for evaluating Finland's imbalances. Duration curve of Finland's hourly imbalances from 2010 - 2012 is shown in Figure 3. Values are presented relative to hourly consumption.

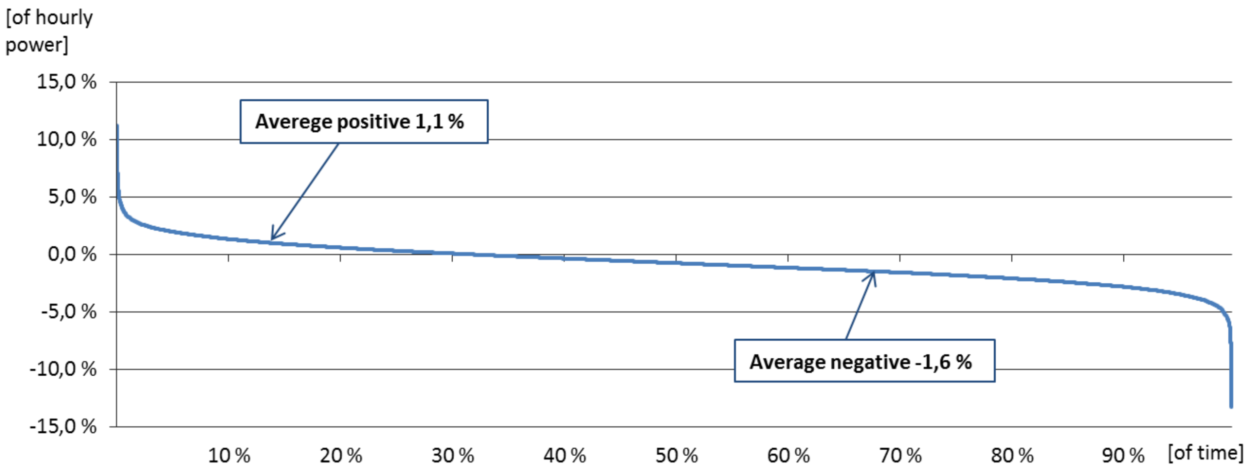

Figure 3 Duration curve of Finland's hourly imbalances from 2010 - 2012 (Data source: Fingrid Oyj 2013a).

Traditionally, production forecasts have been more accurate compared to consumption forecasts because production is easier to plan ahead. However, there are greater uncertainties in wind and solar power forecasting than conventional production forecasting. In consequence, Finland's hourly imbalances will increase when large scale renewable electricity production is integrated in the power system.

In the thesis, it was assumed that average Finland's hourly imbalance will increase by average wind power and solar power forecast error. Average wind power forecast error was determined to be 3 % of installed capacity in 2020 and 2.5 % of installed capacity in 2030 assuming that wind power forecasts are updated intra-daily and forecasting tools will develop. Solar power was taken account only in 2030 situation, and the forecast error then was assumed to be 4 % of installed capacity. These assumptions are based on Danish and German experiences available at (ENTSO-E 2010; Heinemann & Lorenz 2011; IEA Wind 2009) but geographical differences were noted. In Finnish case, it was assumed that wind power will mainly be built in the west coast of Finland and solar power in the southern Finland.

3.2 Intra-hour load variability

Consumption consists of all loads connected to grid at a moment, and thus it varies constantly. Intra-hour load changes were considered on the basis of Finnish consumption in 2010 - 2012. Maximum negative and positive changes (98 % probability) per hour were investigated. Spring, summer and winter were analysed separately. Weekday's data are presented in Figure 4 and weekend's data in Figure 5. Values are presented relative to hourly consumption.

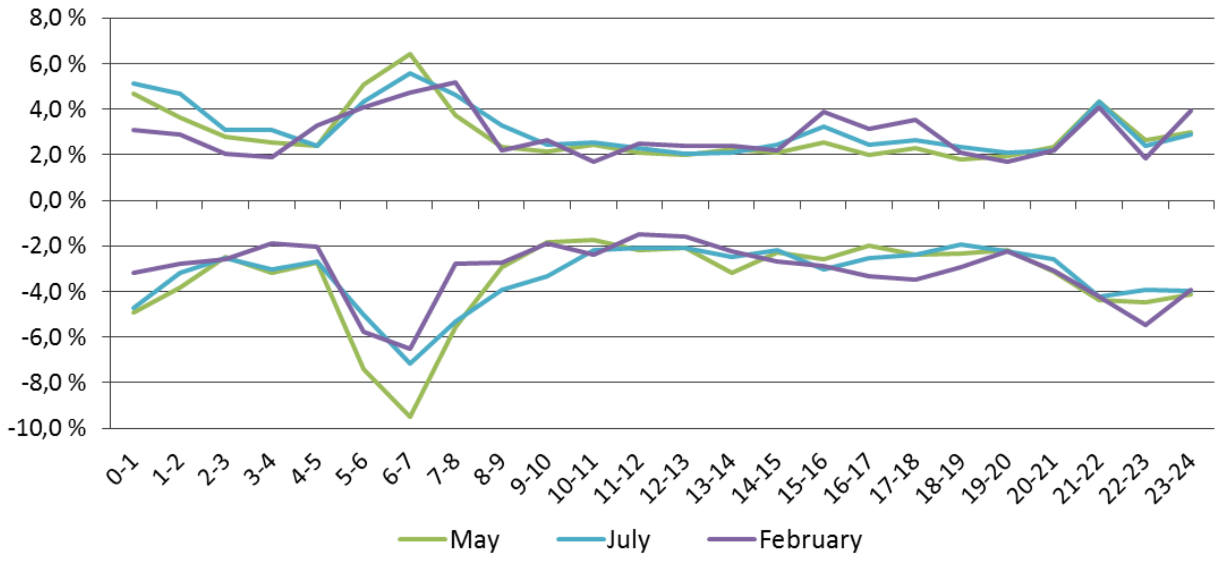

Figure 4 Weekday maximum load intra hour changes for each hour of day in Finland in 2010 - 2012 (Data source: Fingrid Oyj 2013b).

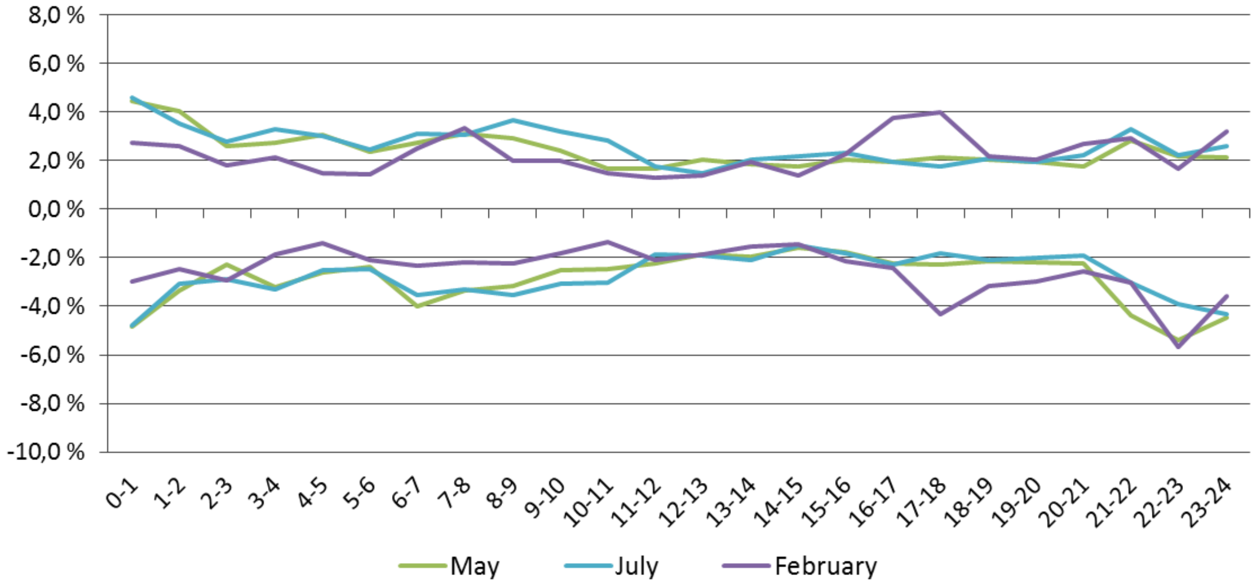

Figure 5 Weekend maximum load intra hour changes for each hour of day in Finland in 2010 - 2012 (Data source: Fingrid Oyj 2013b).

As can be seen in Figures 4 and 5, load changes are typically largest in the morning and in the evening when load is rising or sinking significantly. However, load changes can cause regulation need in other hours of day, too. In the thesis, it was assumed that load will act as today in the 2020s, i.e. load changes are relatively equal.

3.3 Intra-hour wind power and solar power variability

Output of conventional generation is typically quite stabile during operation hour. Intra-hour changes are caused mainly by disturbances. However, variability will increase because wind power and solar power vary continuously depending on weather conditions. In the thesis, it was noticed only intra-hour variability caused by wind and solar power, other generation forms were not considered.

3.3.1 Wind power

Intra-hour wind power variability was evaluated on the basis of West Denmark 5 minute wind power production data from 2012 provided by Danish TSO Energinet.dk. Because variations appear in both up and down directions, the absolute values were considered. The maximum change per hour was formed by comparing 5 minute values to hourly value which was calculated using 5 minute values. The duration curve of maximum intra-hour wind power variations in West Denmark in 2012 is presented in Figure 6. Values are presented relative to installed capacity which was about 3.05 GW in West Denmark in 2012.

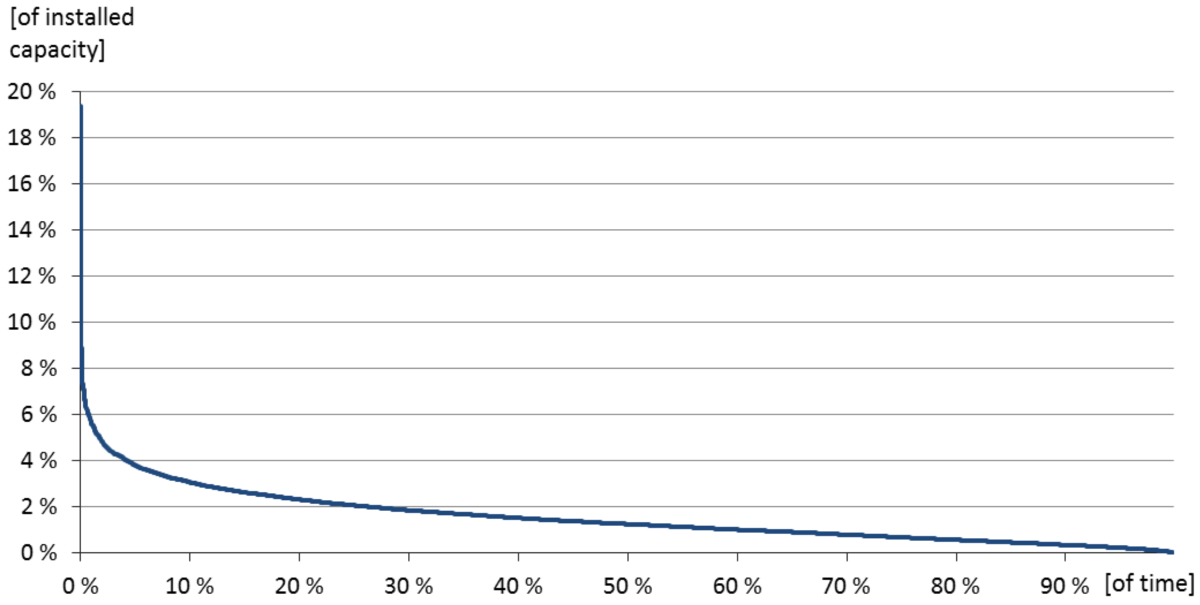

Figure 6 Duration curve of wind power intra-hour changes from hourly average value as % of capacity in West Denmark in 2012 (Data source: Energinet.dk 2013).

As can be seen in Figure 6, about 98 % of time the intra-hour change was 5 % or less of installed capacity in West Denmark in 2012. The largest values are caused by extreme weather situations and/or measurements errors.

West Denmark is significantly smaller region compared to Finland. However, Finland's wind power production will be mainly built in the coastal area. Thus, it was assumed that the correspondent maximum value (98 % probability) in Finland in 2020 will be 4 % of installed capacity.

3.3.2 Solar power

Solar power has characteristic daily production pattern because of the sun movement. Production begins to increase in the morning, is normally highest during mid-day and begins to decline in the afternoon. Production pattern differs in seasons, and weather conditions cause differences between days, too, as can be seen in Figure 7.

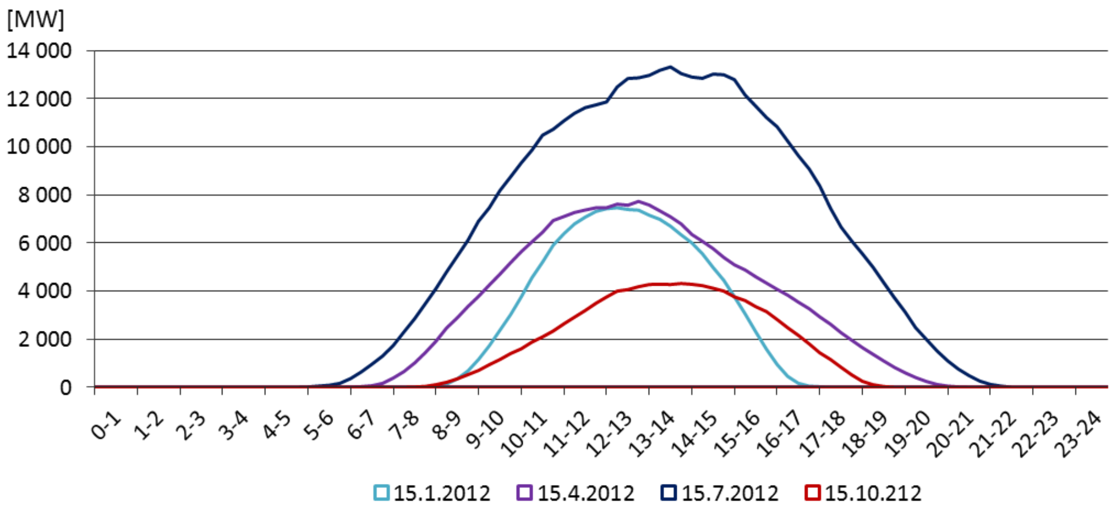

Figure 7 Solar power production pattern in Germany in example days in spring, summer, autumn and winter in 2012 (Data source: Transparency EEX 2013).

Solar power was taken account only in this study's summer 2030 case. Thus, intra-hour variability of solar power was analysed only on the basis of Germany's 15 minute average solar production data from July 2012 available at the Transparency EEX website. The maximum change per hour was formed by comparing 15 minute values to hourly value which was calculated using 15 minute values. Changes were considered relative to installed capacity which was about 30 GW in Germany in July 2012 (Fraunhofer Institute for Wind Energy and Energy System Technology 2012). The maximum changes per hour are presented in Figure 8.

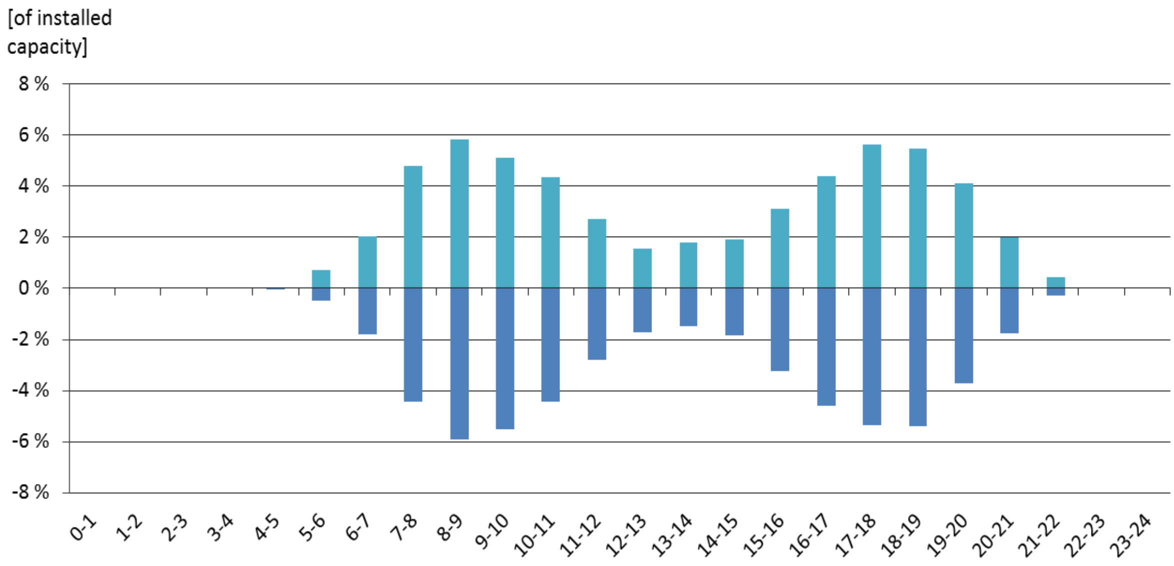

Figure 8 Maximum solar power intra-hour changes from hourly average value for each hour of day in Germany in July 2012 (Data source: Transparency EEX 2013).

As can be seen in Figure 8, the changes are largest in the morning and in the late afternoon hours. German results could not be directly used in the Finnish situation because solar power production was assumed to be concentrated in the southern Finland. In addition, 15 minute average values smooth the variability. Thus, it was assumed that the intra-hour solar production changes in Finland will be 2 % greater than the values presented in Figure 8.

3.4 Extreme events in wind power production

In the thesis, wind power extreme events mean the situations when wind power causes large imbalances. These situations are typically consequences of wind power ramp changes and/or large forecast errors. The largest experienced ramp rate in wind power production in Denmark is about 19 % of installed capacity in an hour. It happened in 2005 during the Gudrun storm (ENTSO-E 2010; IEA Wind 2005). All ramp changes in German in 2010 and 2011 were less than 10 % of installed capacity. On the other hand, ramp rate was over 10 % 42 times in Germany in 2005 (Haase 2012; Rogge 2013). According to Danish and German experiences, it seems that large forecast errors actually happen more often and cause larger imbalances than ramp changes. There have been some forecast errors between 25 - 30 % of installed capacity in day-ahead forecasts in Germany and Denmark during last few years (Hodge at al. 2012).

Both ramp changes and large forecast errors are typically caused by weather front changes. Low pressure fronts, i.e. storm fronts, cause usually the most critical situations. Average, maximum and minimum times per month when storms (wind speed over 21 m/s) have occurred in the Finnish sea area in 1994 - 2012 are presented in Figure 9.

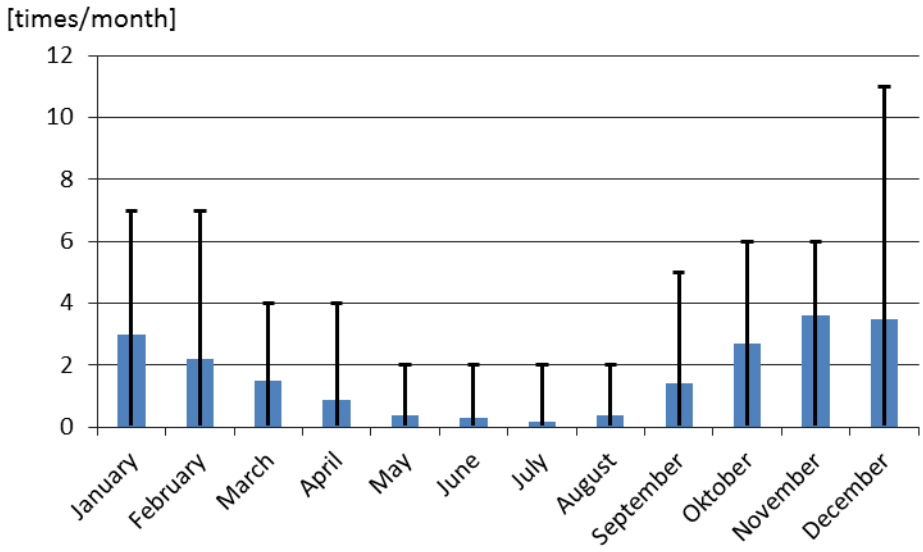

Figure 9 Blue bars present average times per month when storms have occurred in Finnish sea area in 1994 - 2012. Maximum and minimum values are shown with black bars (Data source: Finnish Meteorological Institute 2013a).

These extreme events happen typically only a few times a year. Even though their appearance is predictable, exact timing is difficult to forecast. As Figure 9 indicates, storms are most probable in Finland in autumn and in winter. However, a storm during peak consumption is not probable because there is usually high pressure when temperature is low (Finnish Meteorological Institute 2013b). Summer and spring storms are rare but do occur occasionally. In the case study, wind power extreme event was taken account only in two cases, other in spring and the other in summer.

4 CASE STUDIES

The purpose of the case study was to discover the most challenging situations that can occur in the 2020s. Maintaining power balance is challenging when resources are limited and/or a lot of regulation is needed. Large share of regulations in Nordic is made today with Swedish and Norwegian resources. Finnish resources, mainly hydro power plants and some condensing power plants and combined heat and power plants, take part in the regulating power market, too. Thus, in the case study was considered situations when other Nordic resources could not be utilised because of congestion in the cross-border lines between Finland and Sweden and domestic resources were limited at the same time. The cases represent spring flood time, summer holiday season and winter peak consumption time. Quite low demand levels were chosen in spring and summer cases because regulating resources are typically limited when production capacity in the grid is low. However, high demand levels were chosen in winter peak consumption hours because the problems then are related to adequacy of capacity.

Following method was used in the case studies. First market situation, i.e. hourly consumption level, hourly production for each generation type and cross-border transmissions, was estimated. Then need for balance regulation was calculated on the base of assumptions explained in Chapter 2. Next the amount of market-based regulating resources was estimated. Only up-regulation or down-regulation was considered in each case depending on import and export situation in the Finland-Sweden border. Finally, the difference between regulation need and market-based regulating resources was calculated. If the result was negative, there is a deficit, i.e. the resources can't necessarily cover the need.

4.1 Spring 2020

The difficulties during spring are mainly caused by limited hydro power regulating possibilities because of flooding. In spring, there is typically high import at least from Northern Sweden to Finland because flood season is at the same time in all Nordic countries. Thus, problems are related to up-regulation. Two spring cases were studied, weekday morning and weekend night, both in 2020. The challenge in the weekday morning is that a lot of regulation is needed because the load rises significantly. And in the weekend night case, there is only little flexible capacity in the grid because load is low.

Demand in both cases was set so that about 20 % of time in May demand is under the set levels. Cases represent high flood situation, hydro power production in Finland was set at 2300 MW for each hour in both cases. Wind power output was set at 50 % of installed capacity for each hour. In addition, it was assumed that Olkiluoto 1 or 2 nuclear power plant is in revision as today. Combined power and district heat production was assumed to be low because heat demand is also low when it is warm. No condensing power production was assumed to be in the grid. Cross-border transmissions were assumed so that there was export to the Baltic countries and Russia and import from Northern Sweden. In the weekend night situation, there was export to Middle Sweden and in the weekday morning import. This could be the situation for example when it is calm in the Baltic countries while windy in the Nordic countries and because Nordic electricity is inexpensive because lots of hydro power available.

4.2 Summer 2020 and 2030

Electricity demand as well as heat demand is lowest in summer holiday season. Therefore, many thermal power plants have maintenance outages then. Challenges may occur during minimum load hours when there is only little flexible capacity in the grid and especially down-regulation resources can lack. Thus, export situation (flow from Finland to Sweden) and only down-regulation was considered in the summer cases. Two summer cases, weekend night in 2020 and Sunday midday in 2030, were assessed in the study. Challenge in weekend night results from the fact that load is lowest then. Sunday midday was chosen in order to evaluate how the typical production pattern of solar power affects the power system operation.

Demand in both cases was set so that about 15 - 20 % of time in July demand is under the set levels. Wind power output was set at 45 % of installed capacity for each hour. Nuclear power output was assumed to be 4350 MW in 2020 situation and in 2030 5000 MW. Hydro production levels were set quite low, especially between 4 and 5 pm when demand is at lowest and around noon when solar production is at highest. CHP production was assumed to be near minimum value that is needed to fulfil the low heat demand. No condensing power production was assumed to be in the grid. Cross-border transmissions were assumed to be so that there was export to Sweden and import from the Baltic countries and Russia. This could be the situation for example when the Nordic hydro resources are below average and it is windy in the Baltic area while calm in Scandinavia.

4.3 Winter peak consumption 2020

Peaks in Finnish electricity consumption are in winter. Most of domestic power plants have high production and there is no or only little capacity left to regulate up in the peak hours. Also high heat demand at the same time limits CHP power plant's capability to regulate up. Because domestic generation capacity in Finland doesn't cover the peak consumption there has been typically high import to Finland in peak hours. Thus, only up-regulation and import situation from Sweden were assessed in the winter cases. Both morning peak and evening peak consumption were considered, both in 2020.

Demand was set to correspond actual peak hour demand from 2010 and 2012 plus 10 % increase by 2020. It was assumed in both cases that the peak demand was covered so that domestic generation capacity is fully used noticing typically generation availabilities during peak consumption time. Wind power output was set at 10 % of installed capacity. Condensing power production was assumed to be 1500 MW during the peak hour. Import was assumed to be available only from Sweden. This could be the situation for example when there is cold period also in the Baltic area and Russia.

5 CONCLUSIONS

The cases revealed that in every case regulating resources available might not cover the need. Figure 10 represents the maximum deficits appeared in each case between possibly needed regulation and market-based regulating resources.

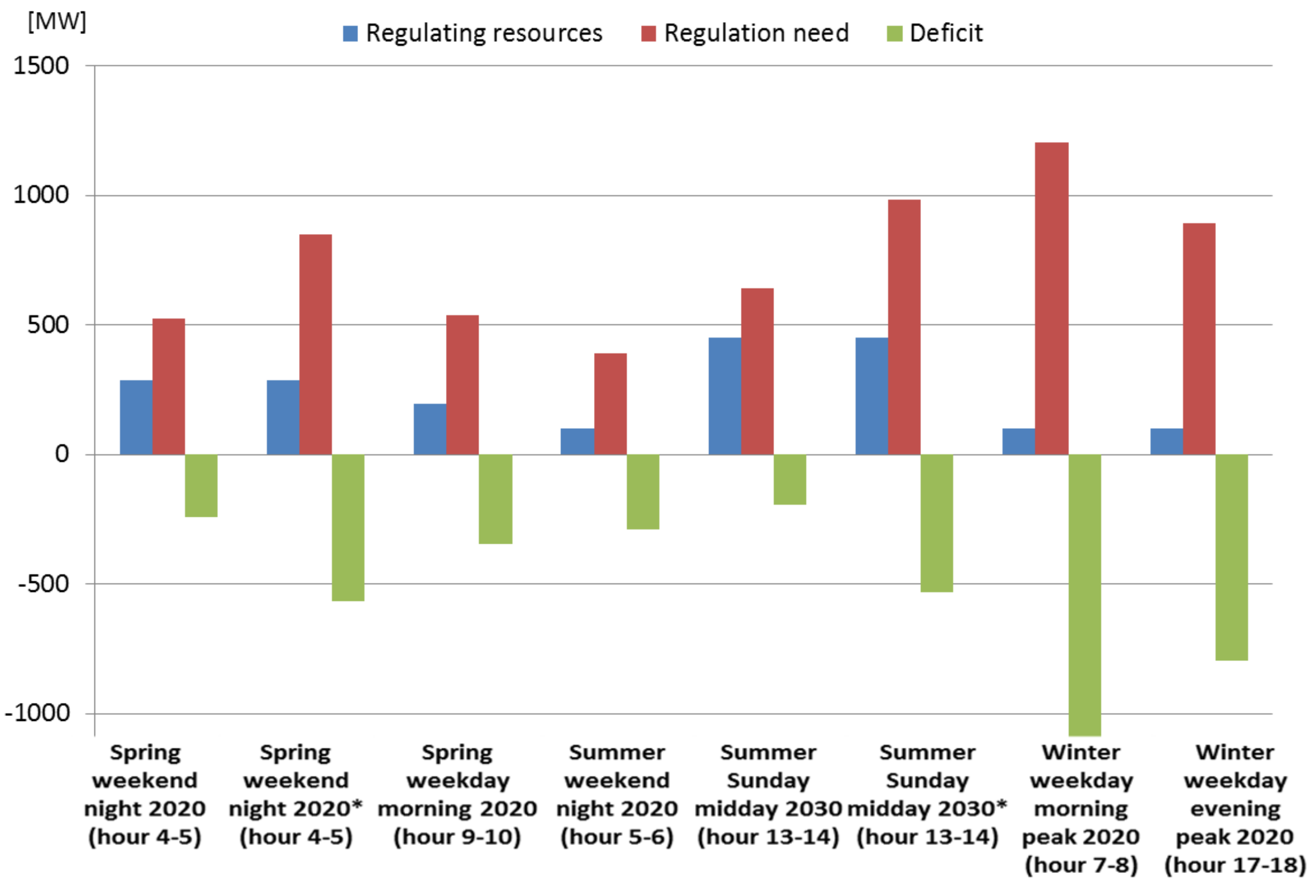

Figure 10 Maximum deficit hour in each case. Extreme wind power situation that were also considered in the spring weekend night case and in the summer Sunday midday case are marked with *.

As the results revealed, challenges will be confronted in the power system operation in the next decade. More regulation will be needed while fewer resources are available. In practise, if enough market-based resources aren't available, TSO would have to curtail load in up-regulation situation and output of power plants in down-regulation situation in order to ensure system reliability. In addition, the imbalance costs would increase significantly.

What can be then done in order to avoid this? There are several options that can be divided in three different sections. The sections and some options are mentioned below.

1) Adding and ensuring regulating resources
    - Increase demand response
    - Increase CHP plant's regulating possibilities
    - Improve readiness of nuclear power's use in regulating
    - Use fast disturbance reserve or wind power production curtailment in wind power's extreme events

2) Cutting and predicting the need for balance regulation
    - Develop more accurate forecast tools for both load and renewable production
    - Follow wind power production real-timely with the help of measurements available from all wind power plants
3) Other possible actions
    - Strengthen cross-border transmission capacity
    - Reserve cross-border transmission capacity and foreign reserves
    - Introduce 15 minute imbalance settlement

Beside these actions, contributions for further development of Nordic regulating power market and possibilities to utilise Baltic and Russian resources are needed.

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