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Challenges and Opportunities for the Nordic Power System

Executive summary

This report summarises the shared view of the four Nordic Transmission System Operators (TSOs) Svenska kraftnät, Statnett, Fingrid and Energinet.dk, of the key challenges and opportunities affecting the Nordic power system in the period leading up to 2025.

The Nordic power system is changing. The main drivers of the changes are climate policy, which in turn stimulates the development of more Renewable Energy Sources (RES), technological developments, and a common European framework for markets, operation and planning. While the system transformation has already started, the changes will be much more visible by 2025.

The structural changes will challenge the operation and planning of the Nordic power system. The main changes relate to the following:

- The closure of thermal power plants.
- The share of wind power in the Nordic power system is rising. Installed capacity for wind power is expected to triple in the period 2010–2025.
- Swedish nuclear power plants will be decommissioned earlier than initially planned (four reactors with a total capacity of 2,900 MW will be decommissioned by 2020) while Finland will construct new nuclear capacity (one unit of 1,600 MW, which will be onstream in 2018 and another unit of 1,200 MW planned for 2024).
- The capacity from interconnectors between the Nordic power system and other systems will increase by more than 50 per cent in 2025. The existing interconnectors and those under construction are shown in Figure 1.

Overview of existing HVDC interconnectors and HVDC interconnectors under construction

Existing	
Skagerrak 1–4	1600 MW
NorNed	700 MW
Konti-Skan 1–2	680/740 MW
Kontek	600 MW
Baltic Cable	600 MW
SwePol Link	600 MW
Fenno-Skan 1–2	1200 MW
NordBalt	700 MW
Estlink 1–2	1000 MW
Vyborg Link	1400 MW
Storebaelt	600 MW

Under Construction	
Cobra	700 MW (2019)
Kriegers Flak	400 MW (2019)
Nord Link	1400 MW (2020)
North Sea Link	1400 MW (2021)

Under development
(not in map, comprehensive list in Appendix 3)

- Viking Link
- DK West – Germany
- North Connect
- Hansa PowerBridge

Figure 1 Overview of existing and planned HVDC interconnectors in the Nordic power system. Only those planned HVDC interconnectors with a final investment decision are included.

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These changes present challenges for forecasting, operation and planning of the power system. Further automatisation and digitalisation of the power system could offer new opportunities within system regulation, and enable consumers to play a more active role. Smart meters, energy management systems, automated demand response and microgrids, are key enablers in the restructuring of the Nordic power system. The Nordic TSOs are developing these enablers both at a national and a Nordic level. There will be an increase in the interconnection of markets, big data processing, price- and system-respondent components and more advanced system-balancing. The system will be more complex, more integrated and more automated, and will require new measures from TSOs, regulators and market stakeholders.

Further development of the currect markets is necessary. Low prices and market uncertainties are clouding the investment climate for new generation capacity and adversely affecting the profitability of existing conventional generation. The capacity mechanisms that are being introduced and assessed in various European countries represent a further challenge. The Nordic TSOs wish to improve the current market design to accommodate these changes.

It is important to adopt a holistic perspective and to plan the transmission grid in relation to the market and the response from both generation and consumption. In order to do this efficiently, the TSOs must have a common understanding of how the changes will affect the Nordic power system and how we can respond.

Figure 2 shows the Nordic TSOs' best estimate scenario of the Nordic energy balances in 2025. The main challenges foreseen by the Nordic TSOs in the period leading up to 2025 include:

- Meeting the demand for flexibility.
- Ensuring adequate transmission and generation capacity to guarantee security of supply and to meet the demand of the market.
- Maintaining a good frequency quality and sufficient inertia in the system to ensure operational security.

These challenges, many of which we are already facing, but which will be more prevalent in the years leading up to 2025, are analysed and discussed in further detail below.

Nordic energy balances 2025

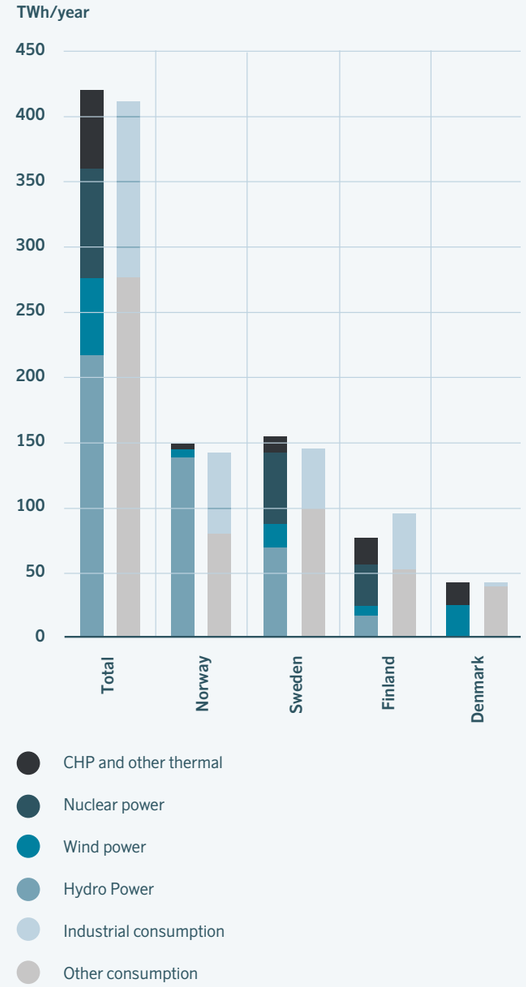

Figure 2 An estimate of production and consumption in the Nordic power system in 2025 as a result of market simulation in 2015.

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System flexibility

One specific feature of the power system is the need to keep power production at the exact same level as power consumption at all times. This requires flexibility, which can be defined as the controllable part of production and consumption that can be used to change input or output for balancing purposes. Intermittent renewable production is a main driver for increasing flexibility demand, whereas existing flexibility resources are limited and to some extent decreasing. Increased transmission capacity towards Continental Europe can provide flexibility in some situations, but also means increased competition for the low cost flexibility provided by Nordic hydro power.

In a well-functioning power market, a severe shortage of flexibility should be avoidable. However, it is uncertain whether the current economic incentives are sufficiently robust. Potential problems include regulatory and/or technological obstacles preventing a transition to a system with a more diversified supply of flexibility, and market designs intended to secure flexible capacity in line with market signals being developed too late.

Another potential challenge could be distortion of the price signals, for instance through unsuitable RES subsidy schemes or fixed prices for end users. Such market imperfections will present challenges for system operation in the coming years. In severe cases, it could lead to hours without price formation in the day-ahead market, and periods of insufficient available balancing resources in the operational hour. It is also possible that these challenges will occur in individual geographical sub-areas even though there is enough flexibility available at system-level.

One prioritised area within TSO cooperation involves developing more knowledge about the technological and economical potential for new flexibility, in order to obtain a more accurate picture of prospective challenges in balancing the system. Other possible solutions that could be implemented by the TSOs include:

- Developing markets to provide the needed flexibility. Finer time resolution in the day-ahead and intraday markets as well as the balancing market, and a stronger emphasis on the intraday markets would reduce imbalances and hence the need to balance resources within the operational hour.
- Utilising transmission capacity more efficiently - evaluation of different capacity methods is ongoing.
- Restrict ramping on each HVDC interconnector even further.

Possible solutions requiring broader collaboration:

- Ensuring that the rules and regulations of the market facilitate the most cost-effective development and utilisation of available flexibility.
- Utilising the AMS meters to further develop demand response.

Generation adequacy

ENTSO-E's adequacy assessment shows that the Nordic power system will be able to cover demand in the Nordic countries in 2025; however, more accurate assessments will be required to obtain a more reliable evaluation of the situation. The ongoing and predicted changes in the power system will make it more difficult and more expensive to fully eliminate the risk of capacity shortages. This implies a need for a clear definition of generation adequacy, and discussions of the socio-economic best instruments to use in order to maintain generation adequacy.

At the moment, low market prices represent one of the main challenges for the Nordic power system. Reduced profitability of conventional power generation will lead to lower capacity of thermal and nuclear power plants. If price signals do not reach market participants, the latter will not respond by regulating production and/or changing demand in shortage/scarcity situations, or investing in new generation. Thus, securing adequate capacity is also a question of getting prices right.

A second challenge relates to the adoption of appropriate methodologies and definitions. Traditional adequacy methodologies are deterministic and therefore disregard capacity based on intermittent power sources. They also underestimate the value of transmission capacity, and do not cover the stochastic nature of component failure in the power system. In addition, the current adequacy assessments and mitigation measures do not fully value cross-border exchange.

Possible solutions that could be implemented by the TSOs:

- Development of harmonised, shared Nordic probabilistic methodologies to address uncertainties in the power system.
- Measures to address adequacy should be identified from a Nordic perspective; however, mitigation measures can be developed on both a national and a regional level. Hence, the Nordic countries need to identify common principles for mitigation measures.

Possible solutions requiring broader collaboration:

- Adequacy is to a large extent a common Nordic challenge which will necessitate ongoing common market development and implementation of common adequacy assessments. In order to achieve this, the regulatory framework will have to adopt common definitions of generation adequacy.
- RES subsidies to be coordinated on the regional level.

Frequency quality

System frequency is an indicator of the instantaneous power balance between production and consumption and power exchange, while frequency quality is a key indicator of system security. Frequency deviations outside the target area challenge system security by reducing the balancing reserves available to address disturbances. Frequency quality is a common feature of the Nordic synchronous system.

Larger imbalances caused by forecast errors and HVDC ramping present a challenge for the TSOs. Maintaining adequate frequency and balancing reserves is critical for securing real-time balance. The current market design, which is based on hourly resolution, does not guarantee momentary balance within intra-hour timeframes. The trend of increasing intra-hour imbalances is expected to continue as a result of faster, larger and more frequent changes in generation and ramping of HVDC interconnectors. More unpredictable power generation in the Nordic power system will result in more forecast errors.

Another challenge is the increased need for, though reduced access to, reserve capacity in the current market situation. Smaller power plants do not provide the same extent of frequency and balancing reserves as traditional plants. When fewer large power plants are in operation, capacity problems can arise, and the system is less well equipped to maintain stable frequencies.

A third challenge concerns the availability of transmission capacity for frequency and balancing reserves. Effective management of grid congestion plays an important role in securing system operation and efficient resource utilisation. It is not possible to regulate resources to balance the system if these are stuck behind a bottleneck. The costs of reserves and availability of transmission capacity vary between areas and over time, which means that the distribution of reserves must be dynamically optimised to ensure that necessary grid capacity is available. This would reduce costs compared with applying fixed distribution of reserves over time.

Possible solutions that could be implemented by the TSOs:

- Clarification of a common Nordic specification for frequency quality, including requirements for frequency and balancing reserves.
- Further development of joint Nordic ICT solutions. Introduction of more advanced systems for supervision and control, and more automatisation of operational processes.
- Develop Nordic markets for all balancing products.

Possible solutions requiring broader collaboration:

- Finer time resolution in the energy and balancing markets.
- Stronger incentives for Balance Responsible Providers to maintain the balance by ensuring correct price signals.
- Review efficient and market based solutions for allocating transmission capacity to balancing and reserve markets.
- Harmonisation of products and market solutions for frequency and balancing regulation.

Inertia

Inertia in a power system is connected to the rate of change of frequency. With insufficient inertia, frequency drops can be too rapid, causing the frequency to reach the load-shedding value before reserves have reacted sufficiently. Higher volumes of RES, phasing out of nuclear units, and high imports through HVDC connections all reduce inertia levels. In 2025 the inertia, measured as kinetic energy, is estimated to be below the required volume of 120–145 GWs 1–19 per cent of the time depending on the climate year (based on analyses with historical reference period 1962–2012). The lowest kinetic energy values are observed during summer nights with high wind production. In the current Nordic power system (2010–2015), the estimated kinetic energy was below 140 GWs 4 per cent of the time or less; however, in 2009 the duration was approximately 12 per cent.

The main challenge lies in maintaining sufficient inertia in the system to guarantee operational security since insufficient inertia would put system stability at risk in the event of a large unit trip.

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Another challenge relates to the lack of minimum requirements i.e. a common understanding of how low a level of inertia the system can accommodate, and expectations of the future Nordic power system. Market solutions or incentives will be required to ensure that sufficient inertia is maintained in the system at all times.

The solutions for coping with low inertia can be split between legislative, market and the TSOs' own measures.

Possible solutions to be implemented by the TSOs:

- Setting minimum requirements for kinetic energy in the system.
- Limiting the power output of the largest units (generators and importing HVDC links) in situations with low inertia, to a level where the frequency remains within the allowed limits in the event of large unit trips.

Possible solutions requiring broader collaboration:

- In the short term, inertia in the system can be increased by running existing production units with lower average output.
- Adding more frequency containment reserves, including HVDC Emergency Power Control, or increasing the reaction speed of the reserves for getting faster responses during disturbances.
- Installing System Protection Schemes or using HVDC links.
- Adding rotating masses, such as synchronous condensers.
- Adding synthetic inertia to the system.

Transmission adequacy

Transmission capacity plays a key role in addressing the system challenges described above. Adequate transmission capacity enables cost-effective utilisation of energy production, balancing and inertia resources and helps to ensure the security of supply.

Each TSO in the Nordic region is responsible for developing the transmission system within its borders. The Nordic TSOs have published national grid development plans presenting both approved projects and project candidates. The very nature of the transmission system makes regional cooperation essential to achieve an effective power system. This is fully acknowledged by the Nordic TSOs, and joint grid development plans have been published since 2002. Identified potential transmission investments are subject to a bilateral study between the involved TSOs.

One challenge of transmission planning involves applying the correct assumptions and properly valuing all benefits. Uncertainty surrounding future developments has increased in recent years, making it more difficult to predict the future power system. In addition, not all power system benefits of transmission capacity are properly valued when evaluating transmission investments. The focus has historically been on commercial benefits, while there is a growing need to adequately value the security of supply. Consequently, there is a need to further develop cooperation with regard to modelling tool development and method improvement. Another difficulty relates to balancing Nordic, European and national perspectives in transmission planning. It is critical to address these issues today in order to successfully deal with predicted system challenges.

A second challenge involves maintaining operational security and an efficient market while reconstructing the grid. While development and increased application of live work will help meet this challenge the planned outages of grid components will nonetheless be very frequent in the coming decade, with resulting intermittently limited capacity. The investment portfolio shows that this is especially relevant for the next few years, since investments for the Nordic TSOs peak in 2018.

Possible solutions that could be implemented by the TSOs:

- Additional transmission capacity can alleviate the challenges with generation adequacy, flexibility and real-time balancing.
- Improving modelling tools and common understanding of the interpretation of findings, along with a robust scenario strategy. Improving methods of including additional values in transmission planning and in-depth analysis of which services that are valuable for the power system.

Possible solutions requiring broader collaboration:

- Clarification of differences and common goals for grid development in the Nordic region.

The way forward

The challenges listed need to be addressed. If no measures are taken, there could be severe consequences. The timeline in Figure 3 highlights the most important triggers (changes) which will exacerbate the challenges. Leading up to 2025 and beyond, the risk of the identified challenges will increase. Action from the Nordic TSOs and other stakeholders in the Nordic power sector will reduce the risk.

Improvement possibilities have been identified with regard to market design and operations. The Nordic TSOs have started several projects, including initiatives to boost knowledge about frequency, quality and handling of inertia; to develop a common market for balancing reserves, more finely tuned time resolution, full-cost balancing, cost-recovery and efficient balancing incentives, to stimulate demand side response and to secure more efficient utilisation of transmission capacity.

More extensive cooperation between the Nordic TSOs is a prerequisite for successful development and implementation of the available solutions; however, the Nordic TSOs cannot achieve everything on their own. Successfully stabilising the power system will require extended cooperation across the power sector. An example where cooperation between regulators and TSOs is necessary is the EU regulatory cross-border cost-allocation (CBCA) tool, which the Nordic TSOs do not believe is an efficient way to speed up market integration.

Possible solutions have been identified for each challenge analysed in this report. Some of these solutions are market based where there need to be an agreement of which market model to develop and implement. Other solutions are technical solutions where cost and cost-sharing are the main issues. A third category of solutions is knowledge related – more insight is needed in order to evaluate the solutions. Many of the proposed solutions cannot be developed and implemented without extensive collaboration with the regulators and the power industry. The power system is becoming more complex and more integrated. Cooperation both across country borders and between different stakeholders in the Nordic power system is a prerequisite for success.

Research, development and demonstrations will also be required, especially where future solutions are unclear, and/or contain new technology or concepts. By further developing the R&D cooperation between the Nordic TSOs, an increased commitment and more efficient information sharing is acheived.

The Nordic TSOs will follow up this report with a second phase that will further examine the solutions identified in this report. The aim of the next phase is to take the cooperation a step further and agree on measures.

Timeline of the identified challenges

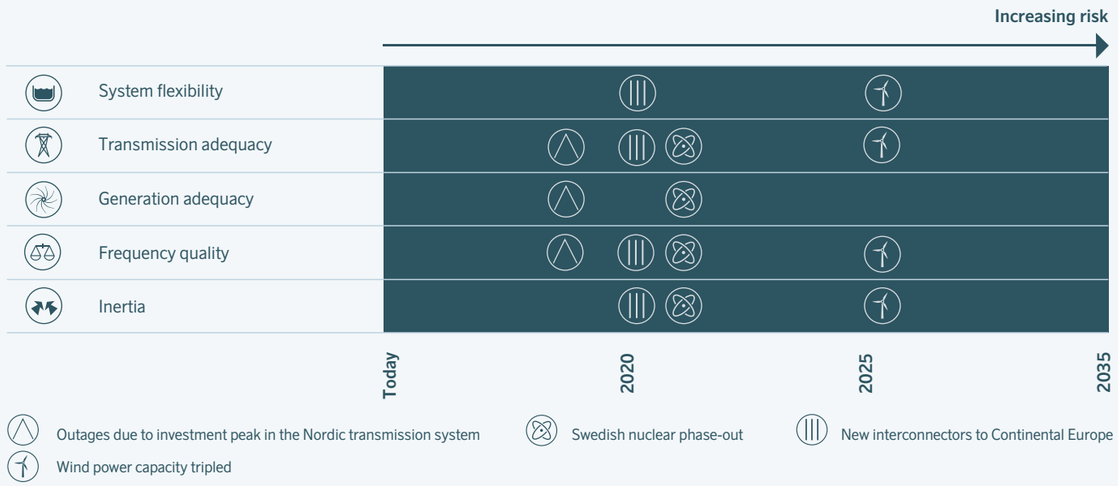

Figure 3 Timeline of the identified challenges. The figure include four triggers (changes) that will exacerbate the challenges. Leading up to 2025 and beyond, the risk of the identified challenges will increase if no measures are taken.

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