Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

The Way forward –
Solutions for a changing Nordic power system

March 2018

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

Content

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

Executive summary

This report summarizes the key solutions that are needed to meet the challenges affecting the Nordic power system in the period leading up to 2025. The report is based on the shared work of the four Nordic Transmission System Operators (TSOs) Svenska kraftnät, Statnett, Fingrid and Energinet. The publication will be updated every second year, and stakeholder events will be arranged to discuss the progress.

In 2016, the Nordic TSOs published the report "Challenges and opportunities for the Nordic Power System" which identified challenges within the five areas of system flexibility, transmission and generation adequacy, frequency quality and inertia. The present report is a common response, outlining coordinated solutions to these challenges.

The power system is becoming more complex and more integrated – cooperation both across country borders and between different stakeholders is a prerequisite for success. The solutions have been developed with input from stakeholders in the sector, and the common workshop hosted by the Nordic TSOs in January 2017 initiated this dialogue. The Nordic TSOs' objective with this report is to support further cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities.

In order to provide an easy overview, the report is structured around roadmaps of the four areas; market, balancing, grid and ICT solutions, and a timeline that gives an updated view of the implementation process. Ch. 1, the introduction, gives an overview of the challenges and the types of solutions that the TSOs are working on, ch. 2-4 explains in more detail the four areas of solutions and ch. 5 discusses the way forward.

Market development. Common market solutions are key tools to ensure generation adequacy, efficient use of the power system, transparent investment signals, and competitive prices for consumers. Important solutions include a higher time resolution, sustainable balance pricing, a new common Nordic capacity calculation methodology and activation of the demand side.

Balancing of the power system. The current balancing model in the Nordic countries builds on controlling the frequency, which increasingly falls outside the limits. An important solution to meet this challenge is a new Nordic balancing concept called the modernized ACE, which the Nordic TSOs reached a cooperation agreement on in March 2018. The agreement covers the required development and operation of common IT tools for supporting common markets, i.e. the development of balancing products that enables harmonization with European platforms. A closer Nordic cooperation to strengthen operational security through the Regional Security Coordination (RSC) office is also an important solution.

Grid development. The Nordic TSOs have identified five main long-term drivers necessitating future Nordic grid investments: Further geographical integration, integration of renewables, Baltic integration, new consumption and the future development of the thermal and nuclear power. The future grid development is based on three principles; common prognosis/scenario, common methodology for cost-benefit analysis and bilateral analysis of corridors.

ICT solutions. Nordic R&D is very closely linked to the overall agenda of digitalization, Big Data and general IT innovation. The Nordic TSOs are commonly developing several IT tools and solutions that will enable an efficient functioning of both markets and system operation.

The way forward. A regional approach for developing the regulatory framework is needed to ensure that policies and measures are efficient, coherent, complementary and sufficiently ambitious. Preparing the Nordic power system to cope with the challenges ahead can only be secured in combining efforts on the three cooperation levels; energy policy, common system solutions and dedicated solutions.

1

Introduction

The Nordic power system is currently undergoing the most substantial changes since the introduction of the common power market more than 20 years ago. The changes are driven by climate policy and technological development, and have led to a changing electricity generation mix with less thermal power and more small-scale, intermittent and distributed power. From 2010 to 2025, installed wind capacity in the Nordic countries is expected to quadruple to 24 GW, which corresponds to approximately 22 per cent of total installed capacity.

On the regulatory side, the ambitious project of creating a single European market for electricity is moving ahead. A central part of this project is a new framework, which harmonises the rules that govern all aspects of the European power system, while concurrently introducing new areas where Nordic cooperation is needed.

At the same time, new grid investments increasingly link the Nordic power system with the rest of Europe, and a digitalization generates more efficient solutions for steering demand and generation.

The result is a power system with new properties and challenges. These challenges are identified and described in the report "Challenges and opportunities for the Nordic Power System" published by the Nordic TSOs in August 2016. The report concludes that the main challenges in the period leading up to 2025 are:

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

With the goal of creating a cost-efficient, secure and green power system, the Nordic TSOs are dealing with these challenges by working on market, balancing, grid and ICT solutions.

Improved market solutions are meant to promote a competitive and efficient delivery of electricity to consumers. This requires solutions that will improve price and investment signals, reduce imbalances, and ensure adequate generation capacity.

1

Introduction

In March 2018, the Nordic TSOs reached a cooperation agreement on a new Nordic balancing concept called modernized ACE (Area Control Error). The agreement covers the required development and operation of common IT tools for supporting common markets. The purpose is to make better use of common Nordic and European reserve resources as well as new technologies and market players, in order to ensure operational security. The new balancing concept and the joint Nordic Regional Security Coordination (RSC) office are important means to achieve efficient system operation.

Grid solutions are required for the efficient development of better market and balancing solutions, as the transmission capacity of the grid determines the physical limits. To ensure efficient coordination, the Nordic TSOs are currently developing common scenarios for a number of cross-border corridors in the Nordic power system, potentially resulting in new projects.

ICT solutions are necessary to enable the efficient functioning of both markets and system operation. Prioritized ICT solutions will enable market transactions as close to real-time as possible and advanced processing of power system data. The Nordic RSC office uses standardized power system data for a coordinated regional calculation of transmission capacity, as well as security and adequacy analysis. This allows the TSOs to operate the Nordic power grid more securely and closer to the limits.

As the power system becomes more complex and integrated, many of the solutions cannot be developed and implemented without extensive collaboration. Cooperation both across country borders and between different stakeholders in the Nordic power system is hence a prerequisite for success.

1

Introduction

1.1 Nordic cooperation on three levels

In practice, the solutions to the power system challenges are developed and implemented through cooperation on three levels:

1. **Nordic energy policy:** High-level political cooperation with a focus on issues such as subsidies, harmonization and generation adequacy. As an example, the report "Nordic Energy Co-operation: Strong today - stronger tomorrow", published in June 2017 by the Nordic Council of Ministers, targets this level. Participants are politicians, ministries, national energy regulation authorities (NRAs), top-management of industry, non-governmental organizations (NGOs) and energy companies.

2. **Common system solutions:** Broad cooperation on issues such as well-functioning power markets, security of supply and Nordic grid development. As an example the TSO report "Challenges and opportunities for the Nordic Power System" originate from this level. Participants are ministries, NRAs, market participants and TSOs.

3. **Dedicated solutions:** Technical cooperation on issues such as timing, alignment of processes and implementation of concrete solutions. The participants are the same as above but the work is more technical.

1.2 Roadmap of dedicated solutions

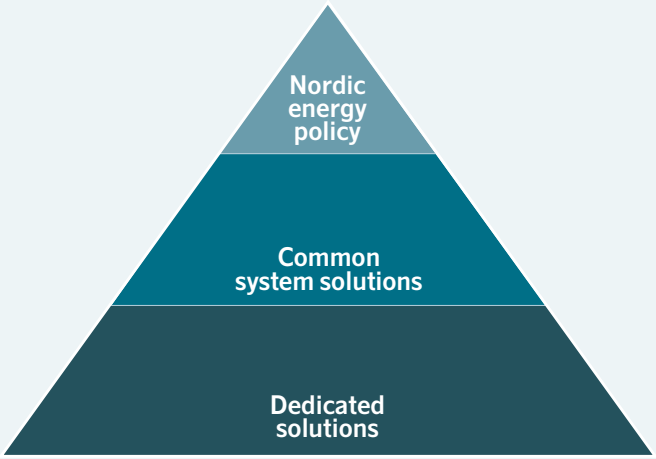
The individual projects presented in this report are dedicated solutions in their own right. However, when viewed collectively we move to level two cooperation. This report is the first of its kind to present a system wide overview of solutions the Nordic TSOs are working on in order to meet the future challenges for the Nordic power system.

In order to provide an easy overview, the report is structured around a Roadmap with four levels related to market, balancing, grid and ICT solutions, and a timeline that gives an updated view of the implementation process.

The objective with this report is to support the cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities. The common workshop hosted by the Nordic TSOs in January 2017, initiated this dialogue. While the Nordic TSOs take the lead in developing these solutions, cooperation with and support from DSOs, market participants, regulators, and the political sphere is needed.

The intention is to up-date this publication every second year and organize stakeholder events to discuss the progress. Up-dated roadmaps will be provided for these events. In addition, stakeholder engagement on dedicated solutions will continue. Our ambition is to lift discussions up to a more Nordic (regional) level. The solutions are further elaborated in the following chapters in the report.

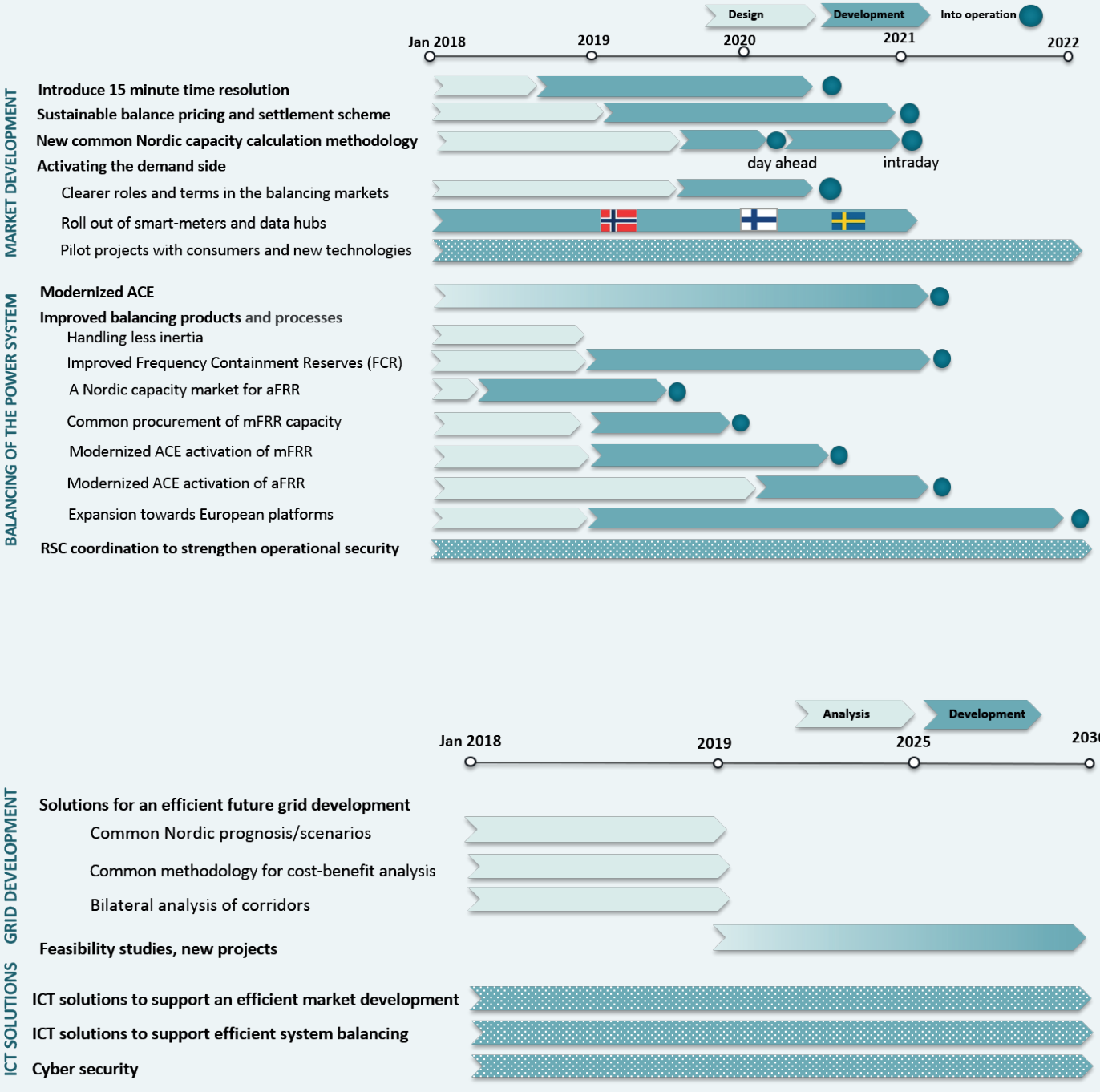
Figure 1. Framework for Nordic energy cooperation



1

Introduction

Roadmaps for market development, balancing of the power system, grid development and ICT solutions



2

Market development – improve market functionality by getting prices right

Common market solutions are key tools to ensure generation adequacy, efficient use of the power system, transparent investment signals, and competitive prices for consumers.

With the current changes to the Nordic power system, new market solutions are required. From the TSOs perspective, an important part of this work is to ensure the continued coherence between market outcomes and the physical laws that govern electricity flows, in order to ensure efficiency and operational security. New market solutions are digitalized, as attested by the national Datahub projects and open data interface projects[1]. Such digital solutions are important for market participants whose information need is increased when markets and operating environment are rapidly changing.

In addition, with the transition to an electricity generation mix with larger shares of intermittent generation and the decommissioning of thermal power plants, the task of ensuring generation adequacy has been given additional attention. The following section elaborates on this aspect, while sections 2.2-2.6 present key market solutions.

2.1 Well-functioning power markets for ensuring generation adequacy

Generation adequacy is essentially a question of whether supply is sufficient to meet demand at all times. While the historical track-record is strong in the Nordic power system, the ongoing transition affects the balance due to changes in both power supply and demand.

In order to shed light on the generation adequacy effects of these changes, the Nordic perspectives on the pan European Mid-term adequacy forecast (MAF), which was published by ENTSO-E in 2017, have been elaborated in a Nordic MAF report. This Nordic MAF report confirms the known tightness in the Finnish system. However, it also indicates that the results in the European MAF report overestimates the problem by setting high outage rates for Finnish nuclear and thermal power plants. Sensitivity analyses in the Nordic MAF report shows that the supply to Denmark and south Sweden may also be vulnerable in very severe situations, depending on the future evolution of the power system.

The chosen sensitivity analyses in the Nordic MAF report include

[1] *Finland and Denmark launched new open data interfaces in 2017*

2

Market development – improve market functionality by getting prices right

additional developments in thermal capacity, Russian exchange, weather patterns, location of wind power and grid constraints. The analyses show that nuclear decommissioning and more extreme weather patterns are important drivers of the risk of load losses. The sensitivity representing low nuclear capacity in Sweden shows that generation adequacy will be challenged over time if not replaced by new sources of flexibility.

The Nordic TSOs believe that three principles should guide our approach to dealing with potential generation adequacy challenges. These principles are further discussed in "Generation Adequacy – methodology for assessment and market measures to secure it", which can be found in Appendix 1. First, generation adequacy challenges are most efficiently dealt with by facilitating well-functioning energy-only power markets, where the prices reflect the value of electricity at all instances. Second, in order to allow for a cost-effective use of the complementary patterns of intermittent renewable energy sources, as well as the trade of energy between surplus and deficit areas - especially in times of system stress - the Nordic TSOs must aim for adequate transmission capacity within and between the Nordic countries, as well as to neighboring regions. Third, time-restricted strategic reserves are preferred to market-wide capacity mechanisms, and only as a last resort if the energy-only market does not deliver a satisfactory supply-demand balance.

While the ambition of the current market setup is an energy-only power market along the lines of the three principles, a number of challenges have been identified. Many of these are presented in the reports "Challenges and opportunities for the Nordic Power System" published by the Nordic TSOs in August 2016, and in "Capacity adequacy in the Nordic electricity market", delivered to the Nordic Council of Ministers by THEMA Consulting Group in 2015.

In order to deal with these adequacy-related challenges, the TSOs have developed an Action plan, which was presented to Elmarknadsgruppen[2] in October 2017. The Action Plan outlines concrete solutions where this is currently possible, and common Nordic TSO ambitions in areas where additional constraints are currently present, e.g. in areas where European regulation is still under development, but open for Nordic influence. Many of the solutions/ambitions outlined in the report require NRA approval.

The Action Plan suggests to improve wholesale price signals by introducing a higher market time resolution (and imbalance settlement period), and by sending a clear signal to market participants that the Nordic TSOs are committed to the continual removal of barriers to correct price signals. This includes a reform in 2017 of the bidding rules for the strategic reserves in Finland and Sweden. In addition, the Nordic TSOs commit to work for a bidding zone structure that reflects structural congestions in the grid, and to improve the capacity calculation methodology to better manage grid constraints, but also to improve transparency of grid operations.

With respect to ancillary services and balancing markets, the Action Plan gives an overview of the work that the Nordic TSOs are currently involved with, such as the harmonization of product requirements, integration of markets, and the improvement of incentives for market participants to contribute to system balancing. Much of this work takes place on a European level.

In addition, The Nordic TSOs support the development of cost-reflective grid tariffs. In the coming years, several of the Nordic TSOs will review their current tariff structure.

While the Action Plan is publicly available, key topics are included and elaborated in the following sections in this chapter, and in Chapter 3 on Balancing. Many of the solutions require new ICT-solutions to enable efficient coordination and cooperation across the Nordic countries. This perspective is elaborated in section 2.6.

2.2 Introduce 15-minute time resolution

Introducing a 15-minute imbalance settlement period will reduce the magnitude of structural imbalances including those generated by ramping of interconnectors. Structural imbalances are a result of market design, rather than stochastic variations. With less structural imbalances, fewer reserves need to be activated. Figure 2 illustrates how a 15-minute imbalance settlement period reduces structural imbalances. The net energy is the same in both figures, but the figure on the right (with the higher time resolution of 15-minutes) also has a net energy balance within each sub-hour time-frame. In this illustrative case, imbalances are reduced by 75 per cent with the introduction

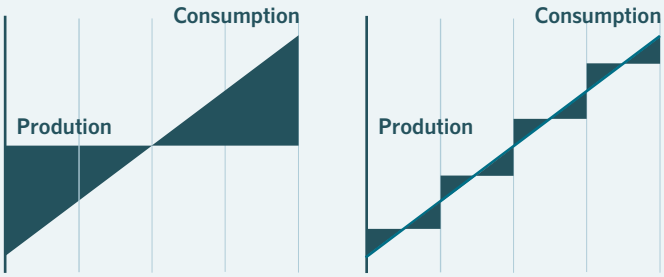
[2] *Elmarknadsgruppen – The electricity market group – is a working group under the Nordic Council of Ministers that intends to further improve the general conditions for the electricity market in the Nordic Region.*

2

Market development – improve market functionality by getting prices right

of a 15-minute resolution. However, achieving this is only possible if the market actors are able to trade away these structural imbalances in a 15-minute intraday market as market participants need to face correct incentives through 15-minutes imbalance prices as well. The time resolution in the balancing market should hence be changed to 15-minute in parallel with 15-minute imbalance settlement period and 15-minute intraday market.

Figure 2. Illustration of how a 15-minute market reduces structural imbalances



Introducing a 15-minute time resolution will also provide new market opportunities for consumers and generators and allow for increased transmission utilization, which ultimately can lead to reduced tariffs. In addition, it will improve the accuracy of incentives faced by market participants.

The Guideline on Electricity Balancing requires TSOs to apply an imbalance settlement period of 15-minute no later than December 2020. The Nordic TSOs have agreed on a common project to implement a higher time resolution, and the ambition is to implement a 15-minute imbalance settlement period and a 15-minute resolution in the balancing and intraday markets by July 1st 2020. Introducing a 15-minute time resolution in the day-ahead market is an ambition in the longer run.

2.3 Sustainable balance pricing and settlement schemes

Correct incentives for market participants to stay in balance are important to achieve generation adequacy and efficient markets, and the imbalance price is the most important incentive given to market participants to trade themselves in balance. Efficient balancing from a socio-economic point of view implies that the imbalance price should equal the marginal cost of balancing. In scarcity situations, balancing is costly. This means that imbalance prices should be allowed to develop to be very high and cost-reflective – including in scarcity situations. As the imbalance settlement period will also be reduced, very high imbalance prices will – all else equal – affect a smaller aggregated energy volume.

In practice, the methodology for pricing imbalances is under review. A common Nordic TSO project has analyzed how to improve incentives to market participants by looking at scarcity pricing, harmonization needs and implications from the inter–TSO settlement.

2.4 New common Nordic capacity calculation methodology

Transmission capacity calculations are a fundamental input in the common power market as they determine the market size. Physically, transmission capacities express the upper limit of how much power that can flow between bidding zones. While the TSO objective is to allocate as much transmission capacity as is socioeconomically efficient to the markets, the allocation must take into account the physical limitations of the grid, including outages and potential faults.

Capacity calculations in the Nordic power system will be coordinated through the Nordic RSC and enhance cooperation among the Nordic TSOs. This will make it possible to utilize existing transmission capacity between bidding zones more efficiently, while at the same time maintaining operational security. In turn, this will lead to more trading possibilities in the power market.

The work on new capacity calculations originate with the Guideline on Capacity Allocation and Congestion Management (CACM), which requires the development of more regional cooperation and the establishment of a common calculation methodology. The default requirement is a Flow Based methodology, which takes into account that electricity flows in AC-grids are not under control by the TSOs, but by the laws of physics. An alternative methodology is the Coordinated Net Transfer Capacity (NCTC) approach, which resembles the current methodology.
The Nordic TSOs have submitted proposal for a new methodology

2

Market development – improve market functionality by getting prices right

to the regulators in September 2017. Implementation of the new methodology in the day-ahead market is planned for mid-2020.

2.5 Activating the demand side

A more responsive demand side would bring benefits, such as reducing the probability of extreme price spikes in the day ahead market, and more flexibility could be made available to the intraday and balancing markets, i.e. a cheaper way of balancing the system. The technical potential for demand side response is big, much of which may be realized without great costs or substantial structural changes. In the balancing markets operated by TSOs, it is of particular relevance to get new participants to enter the market to make up for the loss of thermal power plants.

When discussing the provision of demand side response, it is important to distinguish between different types of consumers. While the flexibility of large-scale industrial consumers is already utilized to some degree in the Nordic countries, the retail consumer is largely a passive player. Currently, most retail consumers have contracts with fixed energy prices, or contracts where the price is variable, but the consumptions is settled based on a generic demand pattern. In turn, there is little incentive to participate in markets for the demand side. Industrial consumers face different entry barriers than retail consumers, and these differences have to be taken into account when designing markets and policies.

Much of the demand response potential is connected at the distribution grid level. Through the Clean Energy Package, the European Commission aims to promote increased regulation of the distribution grid and DSO activities. The Nordic TSOs welcome a strengthened role of the DSOs, and believe that closer TSO-DSO cooperation is beneficial in relation to making the retail customer an active player in the power markets.

In practice, the Nordic TSOs currently work on three types of solutions to activate the demand side:

Clearer roles and terms in the balancing markets: The Guideline

Table 1. Overview of Nordic pilot projects enabling aggregation (installed and planned)

What?	Where?	2016	2017	2018
Demand response pilot	NO4 in Norway			
Enabling aggregation of bids in 10MW volumes in mFRR	NO1 in Norway		X	
Enabling aggregation of bids in 5MW/10MW volumes in mFRR	NO1 in Norway			X
Large scale demand response pilot	NO4 in Norway			X
Pilot of flexible households in FCR-N	SE3 Sweden	X	X	
Pilot of demand side response/ energy storage in FCR-D	SE3 Sweden		X	X
Demand response pilots in different balancing products	Finland	X		
Pilot of independent aggregator and multi-BRP aggregation in FCR-N	Finland	X		
Independent aggregators and multi-BRP aggregation allowed in FCR-D	Finland		X	
5 MW bid size in mFRR	Finland		X	
Aggregation of generation and load in mFRR	Finland		X	
Pilot of independent aggregator and multi-BRP aggregation in mFRR	Finland			X
Independent aggregators and multi-BRP aggregation allowed in FCR-N	Finland			X
Electric vehicle validation for FCR-N	Denmark	X	X	X
Heat pump project testing e.g. sub-meter and hub communication	Denmark	X	X	
Battery project testing mFRR	Denmark	X	X	
Flexibility from industries developing measurements, baseline, pricing etc.	Denmark	X	X	X

2

Market development – improve market functionality by getting prices right

on Electricity Balancing introduces the role of Balance Responsible Party (BRP) and requires TSOs to set national terms and conditions related to balancing. The Clean Energy Package is foreseen to set guidelines for the design of aggregator solutions. Clarifying the roles required to maintain security of supply, allow for increased efficiency in the balancing markets and setting terms for aggregated bids, will make it easier for market actors to participate in balancing and increase the number of available resources. Well-functioning markets with a high level of competition should in the long run provide lower costs for total reserves and allow capacity to be used where it benefits most.

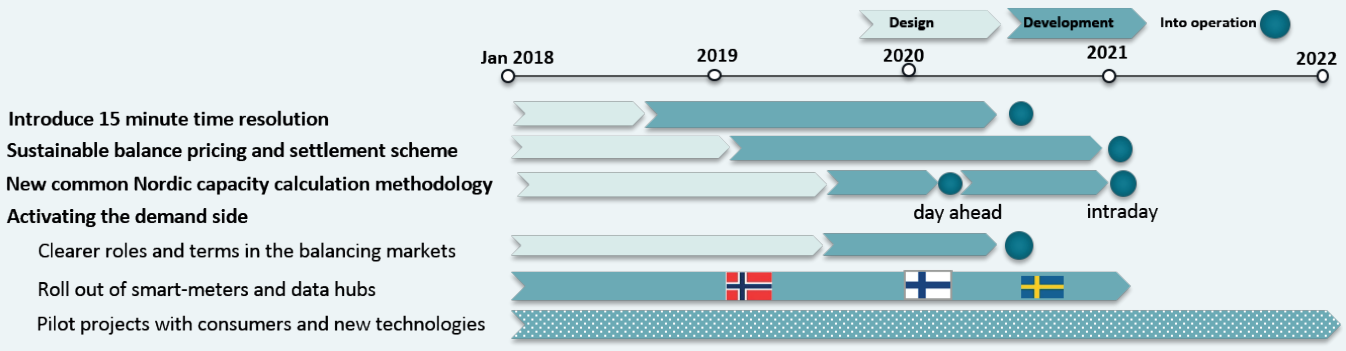
Roll out smart-meters and data hubs across the Nordic region: This is a fundamental prerequisite for the activation of consumers. With the introduction of smart meters and retailers offering contracts with hourly (or perhaps 15 minute) settlements, consumers are given the choice to expose themselves to more price variation, and thereby save costs by optimizing their consumption patterns. As an essential step in solving data access, national data hubs in the Nordic countries are either under development or already in operation. These hubs will provide easy and equal access to consumer data, and will facilitate a transparent and neutral retail market where consumers can make efficient and informed decisions, and where suppliers and third parties can develop innovative services. Looking ahead, linking the Nordic data hubs together could ease the exchange of data across national borders and facilitate an integrated Nordic retail market. With an integrated market, competition for both new and existing market participants will increase, which will benefit Nordic consumers.

Pilot projects with consumers and new technologies: These projects test the barriers to demand side participation. An important part of this is to enable aggregators to open the market for smaller resources. Allowing third parties to aggregate multiple loads and offers will increase flexibility in the market. The recently published paper "Unlocking flexibility – Nordic TSO discussion paper on third party aggregators" discusses this further. Table 1 provides an overview of recent pilot projects.

2.6 ICT solutions to support an efficient market development

The Nordic TSOs are adapting the markets to the European platforms, which implies harmonized rules, processes and information exchange. An adaptation will enable market participants to trade on a pan-European level, but it will also require more data. A close TSO and DSO collaboration will therefore be essential in order to handle large quantities of data and making them available to stakeholders in the most efficient way. In addition, the rapidly changing operating environment in the power markets also increases the need for information. Open data interfaces are one way of making relevant power system information easily available to market participants for carrying out market analyses for trading purposes. In Finland and Denmark open data interfaces were launched in 2017.

Roadmap for the market solutions



3

Balancing of the power system – closer collaboration and customized services

While wholesale power markets ensure the planned balance of supply and demand, they do not ensure operational security of the power system in real-time. This falls on the Nordic TSOs, who are responsible for balancing consumption and generation at every instant. In a secure state, the power system can handle any single fault without resulting in a blackout or involuntary disconnection of demand. The current balancing model in the Nordic countries builds on controlling the frequency and the trend is that the frequency increasingly falls outside the limits, as illustrated in Figure 3. This trend needs to be reversed to ensure operational security of the power system – the system requires more activation, smaller bid-sizes and more automatization.

The current Nordic balancing model also lacks the prerequisites for taking advantage of the ongoing European harmonisation in the balancing area. This could bring wider balancing markets to the Nordic Region, enabling a cost-efficient use of resources within the region by increasing the trade of flexible resources with Continental Europe. The Guideline on Electricity Balancing includes a harmonization package of standard products and introduces common platforms for exchange of balancing products. This will affect the balancing process and the products in the Nordic region.

3.1 Modernized ACE – a new balancing concept

The new Nordic balancing concept involves a transition from controlling the frequency to an ACE (Area Control Error) based concept similar to Continental Europe. Compared to the standard ACE based operation, the new concept will apply cross border activation of imbalance netting and balancing reserves (aFFR and mFFR). We call it modernized ACE. The concept builds on controlling the balance in individual bidding zones, as illustrated in Figure 4, while using powerful ICT solutions. This will enable efficient netting of imbalances and trade between bidding zones, while considering network constraints all the time.

The new balancing concept will allow for a more efficient activation, smaller bid-sizes and more automation. While ensuring clear roles and responsibilities among balancing participants, the main benefits from the new balancing concept include better opportunities for harmonization with and participation in the forthcoming European balancing markets and a more efficient procurement of balancing

Figure 3. Frequency deviations 2003-2017

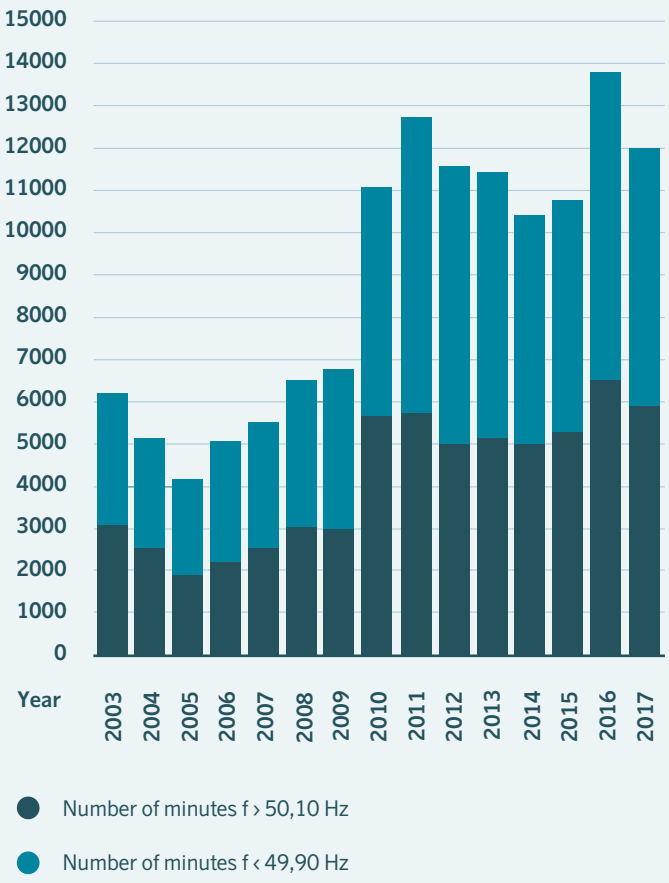
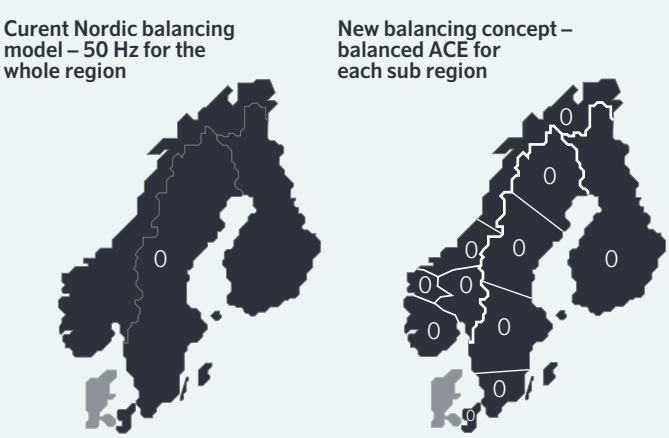


Figure 4 . Illustration of the new balancing concept



3

Balancing of the power system – closer collaboration and customized services

products[3]. Furthermore, the new balancing concept improves frequency quality. Each of these elements contribute to an increased security of supply.

Continued development and implementation of the new balancing concept means comprehensive work during the gradual implementation over the next four years, not least because of necessary new ICT solutions. In order to ensure an efficient process, stakeholders will be engaged throughout the process.

3.2 Improved balancing products and processes

The balancing services in the Nordic countries consist of several products: Frequency Containment Reserves (FCR)[4], automatic Frequency Restoration Reserves (aFRR) and manual Frequency Restoration Reserves (mFRR). These are activated to contain and restore the frequency. Until the FCR has been activated, the inertia response and system damping reduce the frequency drop below unacceptable levels. The FCR is restored when the aFRR and mFRR have been used.

Figure 5 explains the present balancing services in the Nordic countries. The development of a new Nordic balancing concept involves the creation of new balancing products, and the improvement of existing ones. This section presents a progress overview for selected products.

Handling less inertia

Inertia (rotating mass) is vital to ensure stability in the power system. In the future, a larger part of the generation mix will produce power without simultaneously providing inertia. Furthermore, import on HVDC-lines do not contribute with inertia. Therefore, situations with large imports to the Nordic system can result in insufficient amount of inertia in the system. A power system with low inertia will be more sensitive to disturbances, i.e. have smaller margins for keeping frequency stability. This is not satisfactory.

As the Nordic TSOs have the responsibility to ensure that the power system is secure enough to handle system disturbances, new solutions are being developed to ensure there is enough inertia in the system at all times. While they are work-in-progress the focus is to:

Figure 5. Frequency before and after an event

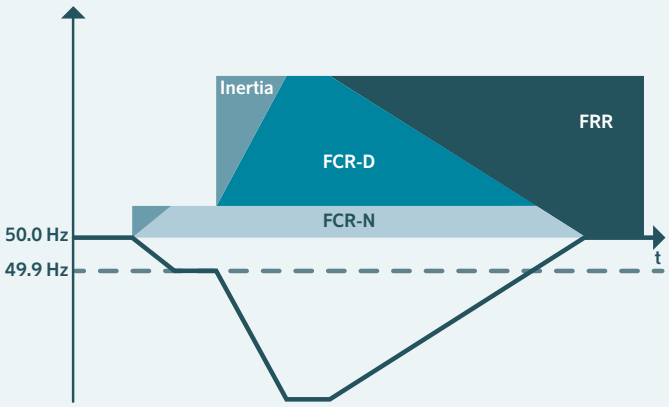


Figure 5. The graph illustrates the frequency before and after an event (e.g. loss of production). It shows the relation between balancing services that are activated to contain and restore the frequency. FRR includes both aFFR and mFRR. The role of the inertial response is indicated.

- Implement simple and robust remedial actions for handling low inertia situations. Within this, explore the possibilities for new, faster frequency reserves. However, until these are in place, limiting the size of the largest possible disturbance (i.e. lowering the output of the largest generation units connected to the Nordic power system) may be needed to handle low inertia situations.
- Improve situational awareness with a more accurate real-time estimation and a tool for forecasting inertia.
- Develop cost-efficient long-term measures to ensure adequate inertia and system security.

Analysis indicates that a market solution for ensuring a certain level of inertia in the system is not the most efficient solution for the Nordic system at the time being within the 2025 time horizon.

Improved Frequency Containment Reserves (FCR)

To meet the future requirements of the power system the technical specification of FCR needs to be adjusted to ensure operational security in both normal and alert state operation. Finding a more optimal specification for FCR requires a trade-off between system needs and sufficient participation in the market. Potential solutions include:

[3] This includes a more efficient and increased procurement of automatic frequency response reserves (aFRR) – capacity and energy - and a common Nordic procurement of automatic and manual FRR capacity, with daily dynamic reservation of transmission capacity between bidding zones.
[4] FCR contains two different products – FCR-N (Frequency Containment Reserves for Normal operation) and FCR-D (Frequency Containment Reserves for Disturbances)

3

Balancing of the power system – closer collaboration and customized services

- The development of a joint Nordic frequency quality target reflecting the target for system security.
- A fine-tuning of the FCR requirements based on feed-back from stakeholders.
- Implementation of a Nordic FCR market.

New Nordic market for aFRR

Introducing a common capacity market for aFRR in the Nordic power system is a corner stone in the new balancing concept. With the introduction of common Nordic aFRR capacity procurement with daily dynamic reservation of transmission capacity between bidding zones as well as cross-border activation, the availability of balancing resources is expanded. This will improve the flexibility in the Nordic power system. The new Nordic balancing concept will also introduce the option for market participants to provide voluntary aFRR bids close to real time.

This is a needed step towards harmonization with Continental Europe, and it improves the opportunity for the Nordic countries to take advantage of the coming European PICASSO platform for aFRR energy activations.

Common Nordic procurement of mFRR capacity

In addition to aFRR, the new balancing concept introduces common Nordic capacity procurement of mFRR – also with daily dynamic reservation of transmission capacity between bidding zones.

Modernized ACE activation of mFRR

The first major milestone in the implementation of the modernized ACE balancing concept is the introduction of a new activation method for mFRR activation. In ACE operation, each TSO will be responsible for activating mFRR for their own LFC areas (bidding zones). The TSOs will for every 15-minute period request a volume per LFC area, and will eventually use the new European standard products for balancing energy. A central Activation Optimization Function (AOF) will secure an optimal use of the cheapest bids and an efficient and safe use of available transmission capacity.

This development is in line with the European development with common platforms for balancing energy activation. When the European platform, MARI, is put into operation, the Nordic countries will be part of a European market for mFRR activation.

Modernized ACE activation of aFRR

The implementation of the modernized ACE concept is completed by the new energy activation market for aFRR. Each LFC area (bidding zone) will have their own aFRR controller regulating the power balance in the area, including energy bids for aFRR and price based activation, according to a Merit Order List. A central Activation Optimization Function (AOF) will secure optimal use of the cheapest bids and effective and safe use of available transmission capacity.

This development is in line with the European development with common platforms for balancing energy activation. When the European platform, PICASSO, is put into operation, the Nordics will be part of a European market for aFRR activation.

Expansion towards European platforms

The introduction of common Nordic capacity procurement of Nordic mFRR will expand the mFRR market. The Nordic TSOs are working on improvements, such as electronic activation of bids, which will open the market to more participants by allowing lower minimum bid size. In the future the Nordic platform will also connect to the European MARI platform for the activation of mFRR energy. The Nordic TSOs have not yet taken a position on the potential use of the European TERRE platform for exchange of the slower Replacement Reserves (Activation time of 30 min).

3.3 RSC coordination to strengthen operational security

The new generation patterns lead to increasing and more fluctuating power flows across Europe, and hence an increased need for closer coordination in the daily operations of the power systems.

The Nordic TSOs respond to this development through enhanced coordination and operational collaboration in all timeframes of operational planning and daily operation. The newly established Nordic Regional Security Coordination (RSC) office is a cornerstone in this Nordic TSO cooperation. The RSC office will provide five core services to the TSOs in the operational planning phase and support the TSOs to optimize the

[5] PICASSO stands for Platform for the International Coordination of the Automatic frequency restoration process and Stable System Operation"

3

Balancing of the power system – closer collaboration and customized services

daily operation of the national power systems, see figure 6.

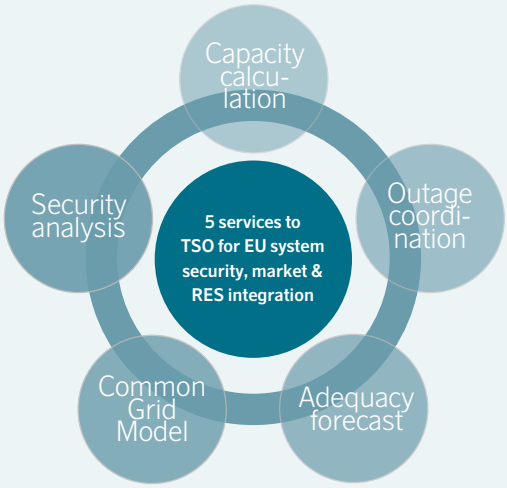
The Nordic TSOs agree with the European Commission on the direction of closer cooperation between TSOs. Continuous capacity calculation and additional coordinated regional system analysis are likely to be developed to support TSO decision-making processes. Experiences gained from the implementation of the first regionally coordinated services in the Nordic RSC will help guide future improvements in regional TSO coordination.

3.4 ICT solutions to support efficient system balancing

The new balancing concept requires substantial developments in the area of ICT and digitalization, although many of the IT tools are for internal use. The Nordic market for aFRR, however, requires a new platform for the market participants in order to facilitate cross-border trade in the Nordic region closer to real-time. More generally, the harmonisation of modernized ACE with the balancing models of Continental Europe involves advanced ICT solutions to ensure efficient coupling with European exchange platforms such as PICASSO, MARI and TERRE. This includes the creation of common market modules and near real-time systems for awareness and forecasting.

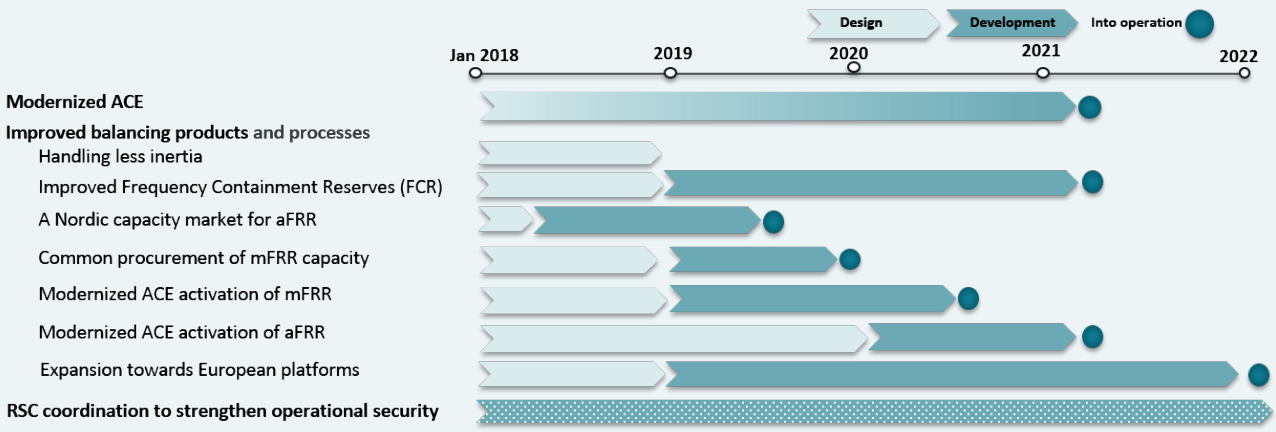
The RSC office contributes to maintaining security of supply in the Nordic region by exploiting the standardized data models for the European power system. New ICT solutions using these large quantities of data allow for regionally coordinated calculations and analyses of grid security and capacities.

Figure 6. Services provided by the Nordic RSC office



The TSOs physical (grid management and operation) and digital worlds will become intertwined as information about the physical assets can be made available anywhere. One of the more promising developments is the emergence of data and analytics tools that can be used to find, manage and analyze data from operational technology, for business purposes. The IMPALA project, which is more detailed explained in chapter 5.3, is an example where the combination of artificial intelligence and big data is used to forecast imbalances, which allows market participants to optimize their business.

Roadmap for the balancing solutions



4

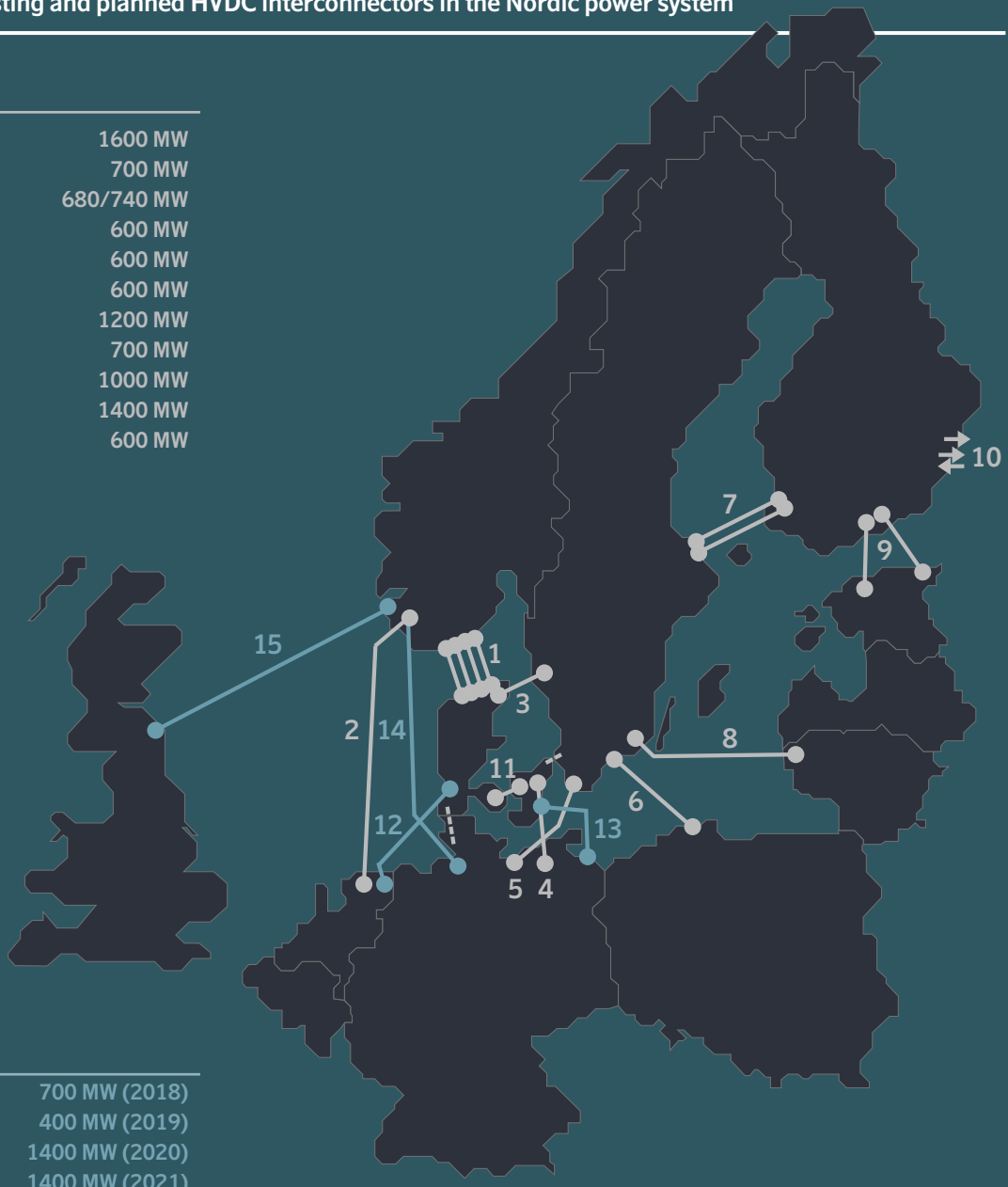
Grid development – planning with a regional focus in a European context

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

Figure 7. Overview of existing and planned HVDC interconnectors in the Nordic power system

Existing

1 Skagerrak 1–4	1600 MW
2 NorNed	700 MW
3 Konti-Skan 1–2	680/740 MW
4 Kontek	600 MW
5 Baltic Cable	600 MW
6 SwePol Link	600 MW
7 Fenno-Skan 1–2	1200 MW
8 NordBalt	700 MW
Estlink 1–2	1000 MW
10 Vyborg Link	1400 MW
11 Storebaelt	600 MW



Under Construction

12 Cobra	700 MW (2018)
13 Kriegers Flak	400 MW (2019)
14 Nord Link	1400 MW (2020)
15 North Sea Link	1400 MW (2021)

Under development

Viking Link
DK West – Germany
North Connect
Hansa PowerBridge

Only those with a final investment decision are included in the map.

4

Grid development – planning with a regional focus in a European context

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

Strong transmission networks facilitate a cost-efficient transition to a green power system, as they enable an efficient cross-border utilization of power production. In addition, they enable the exchange of system services, and remain a prerequisite for ensuring a further integration of markets.

4.1. Current grid development

As outlined in the Nordic Grid Development Plan 2017 (Appendix 2) large amounts of new renewable generation are expected to be built in the Nordic countries, especially in the northern parts of Sweden and Finland. This will significantly increase the north-south flows. In order to facilitate an efficient transmission of the energy surplus in the north to the consumption centers in the south, new transmission lines are needed. In addition to new lines within the Nordic region, planned new HVDC-lines will strengthen the integration of power markets towards Continental Europe and UK.

The Nordic Grid Development Plan shows that ongoing and near-future investments in the Nordic grid are at a historic high, cf. figure 8. The main drivers behind this development are the integration of renewables, further integration towards other synchronous areas, the need for a sufficient level of security of supply, and the need for reinvesting in an ageing Nordic grid.

The high investment levels across the Nordic TSOs reflect investments within Nordic countries, as well as cross-border projects. The cross-border projects in the Nordic Grid Development Plan 2017 are shown in Table 2.

While allowing for increased trade within the Nordic region and with Continental Europe, large HVDC-lines also challenge the system operation because of large variations in power flows from one hour to another. Market design changes such as higher time resolution in wholesale power markets, cf. section 2.2, are necessary to mitigate this challenge and to contribute to the efficient use of the grid.

Figure 8. Total investments by the Nordic TSOs

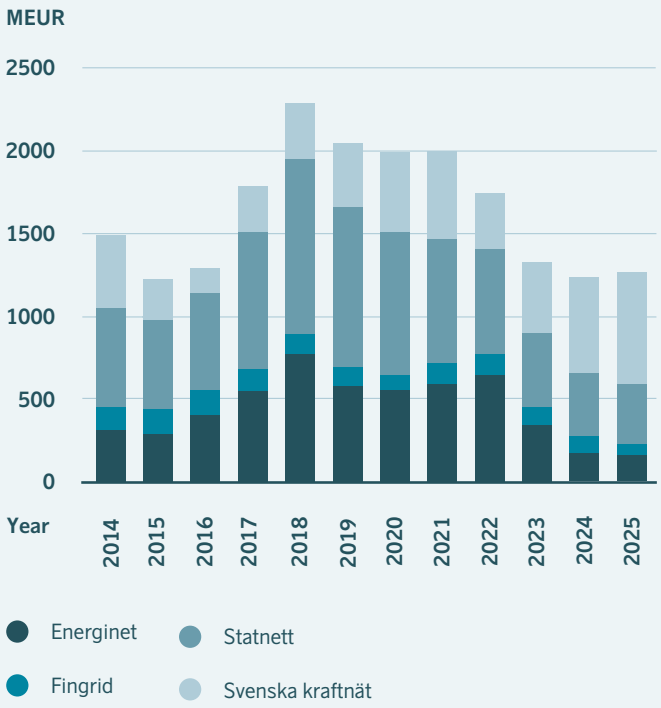


Table 2. Major cross border projects in the Nordic Grid Development Plan

Project(s)	Main drivers	Maturity
Estlink 2, NordBalt Skagerrak 4	Market integration	Commissioned
NordLink, North Sea Link, Cobra	Market integration	Under construction
Kriegers Flak	Renewables integration	Under construction
North-South reinforcements in Norway, Sweden, Finland	Renewables integration, Nuclear decommissioning, New consumption	Under construction/ Planning Analysis
Viking Link, Hansa Power Bridge DK West –Germany	Market integration	Analysis
Third AC-line Sweden-Finland	Market integration, System adequacy	Planning
Fennoskan 1 reinvestment	Market integration, System adequacy	Analysis

4

Grid development – planning with a regional focus in a European context

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

4.2 Future grid development

The Nordic TSOs have identified five main long-term drivers necessitating future Nordic grid investments. They relate to both the current trends in the European power markets and to the specific characteristics of the Nordic region.

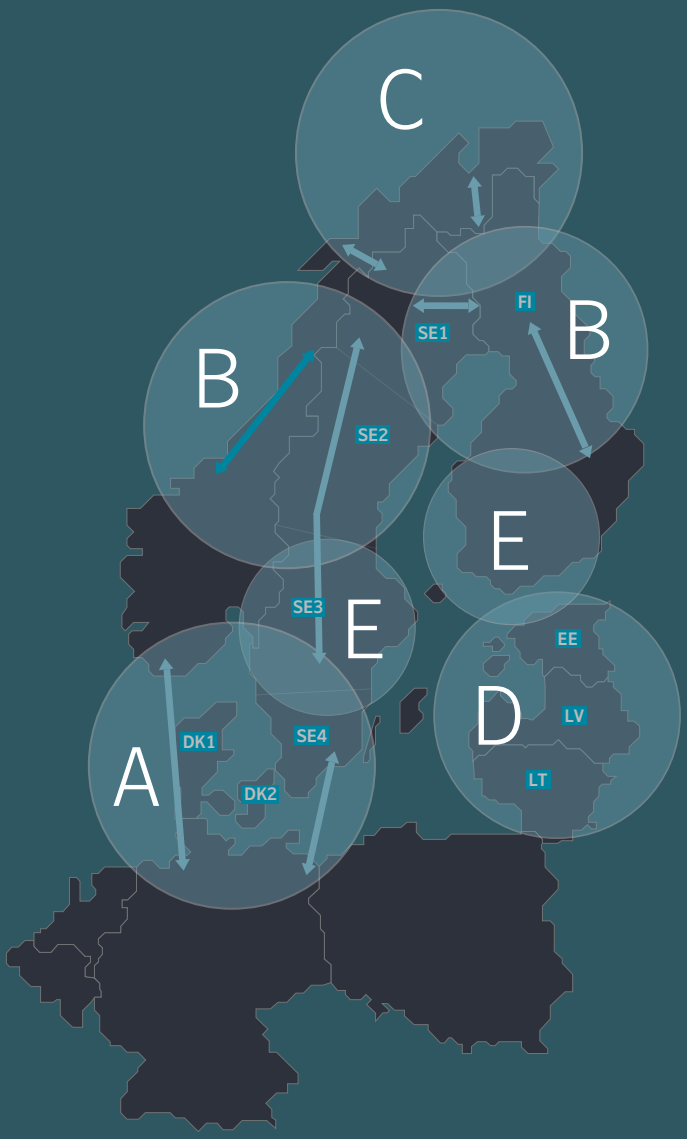
A. Further integration between Nordic countries and the Continental Europe/UK

The annual generation surplus is likely to increase in the Nordic power system (even if nuclear is decommissioned), which makes it beneficial to strengthen the capacity between the Nordic countries and Continental Europe/UK. This increases market integration as well as it furthers the value creation of renewables. In addition, it is beneficial to further connect the Nordic hydro-based system to the thermal-based Continental and wind-based Danish system, for balancing purposes, especially when large amounts of renewables are connected to Continental Europe.

B. Integration of renewables

Based on the political goals of reduced CO_2-emissions and on the decreased cost of wind and solar, further integration of renewables is expected in the Nordic countries. Both the renewables and the integration towards other synchronous systems lead to a need for increased north-south capacity.

Figure 9. Focus areas for grid development in the Nordic region



4

Grid development – planning with a regional focus in a European context

C. New consumption

New consumption patterns are also expected to drive the need for new grid investments. In the far north, the establishment of new power intensive industries such as mines, and the shift from fossil fuel to electricity in the petroleum industry, could create a need for substantial reinforcements. The general trend with electrification of transportation, consumption increase in the larger cities etc. also puts focus on security of supply.

D. Baltic integration

To improve energy security, the Baltics aim to de-synchronize from the Russian power system. Based on an agreement between the involved Baltic Energy Market Interconnection Plan Member States, synchronization with the Continental system is the preferred alternative. The Baltic-Continental synchronization will lead to a potential increased north-south-flow (Sweden/Finland-Baltic-Poland), which has to be further investigated.

E. Future for the thermal and nuclear power

A substantial proportion of nuclear power plants, especially in Sweden but also in Finland, are expected to be decommissioned in the 2030 – 2040 horizon. This would lead to an increased system adequacy risk. In Finland, new nuclear power plants might keep the nuclear production in Finland on the pre-decommissioning level. However, it will require grid investments, as new plants are planned in other locations than existing plants. Nuclear power has many important features in today's system, and a phase out would probably require new generation capacity, grid development, as well as further development of system services.

4

Grid development – planning with a regional focus in a European context

Statnett
FINGRID
ENERGINET
SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

4.3 Solutions for an efficient future grid development

The future grid development is based on three principles - each of them being important solutions for an efficient future grid development:

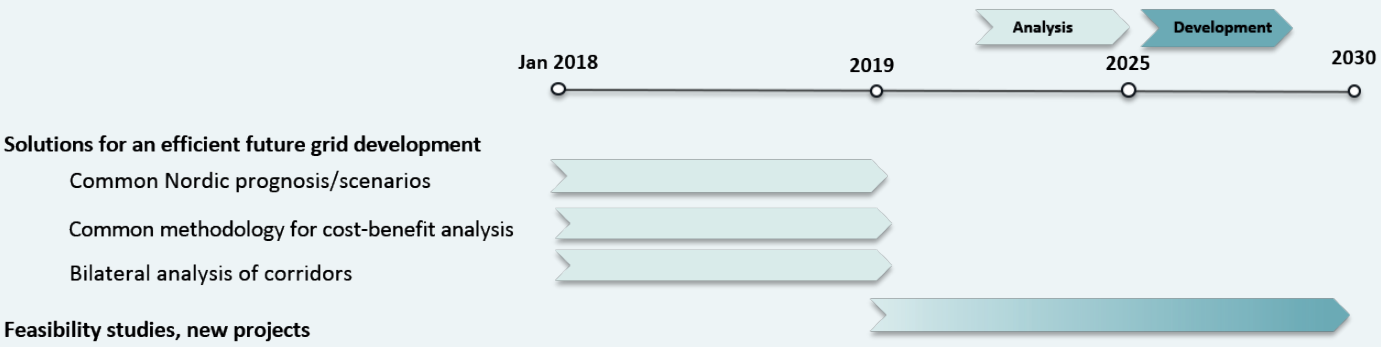
Based on the European scenarios (Ten Year Network Development Plan 2018), the Nordic TSOs will qualify **Common prognosis/ scenarios**, especially taking into account the view of the Nordic TSOs.

Common methodology for cost-benefit analysis: Based on the European methodology, which has been adopted by the European regulation, the Nordic TSOs will make agreements on how to implement the cost-benefit analysis methodology into the Nordic planning process.

Bilateral analysis of corridors: Based on the identified drivers, the Nordic TSOs see a need for further analysis of cross-border corridors in the Nordic system, potentially resulting in new projects. The corridors to be analyzed are: Norway-Denmark, Norway-Sweden (NO1-SE3), Norway-Finland, Sweden-Finland (SE1 and SE2) and Sweden-Denmark. The intention is to present the results from these analyses in the Nordic Grid Development Plan 2019.

Figure 10. Bilateral analysis of corridors

Roadmap for the grid solution



5

The way forward

5.1 A more common regional framework is a prerequisite for efficient solutions

A regional approach for developing the regulatory framework is needed in addition to European regulation, to ensure that policies and measures are efficient, coherent, complementary and sufficiently ambitious. It should also be noted that common and standardized ICT solutions only make sense if the market design and rules are harmonized.

The Nordic TSOs commonly acknowledge three areas where a regional focus is particularly important:

1. The TSOs are analyzing potential long-term solutions for achieving more flexibility, but the realization of this potential depends on the incentives for market participants to provide the flexibility. These incentives are created by well-functioning energy-only power markets, where the prices reflect the value of electricity at all times.

2. A common framework for renewable energy subsidies; a harmonization of efforts and schemes will ensure that the regional system perspective is taken into account.

3. A common framework would be useful in the allocation of transmission capacity for balancing and reserve markets. This should be based on market solutions within a regional context.

5.2 Integration of digital solutions requires a focus on cyber security

To make use of the opportunities that digitalization provide, the Nordic TSOs commit to facilitating a further application and development of new technologies by providing access to data, adjusting market rules and empowering consumers.

ENTSO-E will play an important role in regards to access to Big Data on a pan-European level. It is important that Member States and the European Commission support the definition and implementation of common data exchange format and standards that ensure interoperability between all stakeholders.

The drawback of digitalization and Big Data is the issue of Cyber Security. New market solutions will require high security standards, which entails high costs. An important solution in this regard is to create and implement security standards on Cyber Security, including a common exchange agreement and a security plan. ENTSO-E has a task on this. On a Nordic level, the RSC office is engaged in the development of security standards, including information security, and a Nordic group coordinates cyber security on a Nordic level.

5.3 Nordic cooperation on R&D paves the way for a more automated system and future solutions

R&D is needed to address the current and future challenges for the Nordic and European power system and to pave the way for future solutions. In addition, a good innovation strategy increases efficiency and identifies cost-effective and safe solutions. Currently the Nordic TSOs have 14 on-going joint R&D projects.

Nordic R&D is very closely linked to the overall agenda of digitalization, Big Data and general IT innovation. Several of the IT tools the TSOs develop will improve internal processes but will be of little significance for the outside world. There are, however, two projects worth highlighting which aims to generate solutions to the challenge of maintainting a good frequency quality to ensure operational security, which is of high relevance for all stakeholders.

1.SPARC – SynchorPhasor-based Automatic Real-time Control – is a joint knowledge-building project between the Nordic TSOs driven by Sintef Energi and sponsored by the Research Council of Norway. The primary objective of the project is to develop new knowledge, methods and tools for automatic control and protection of transmission systems based on synchrophasor data. The methods and tools will help the Nordic TSOs improve stability and robustness to contingencies, and by this contribute to future stable and secure operation of the Nordic power system with an increased share of renewables and HVDC interconnections.

2.IMPALA is a joint project between Statnett and Svenska kraftnät where the purpose is to deliver a system that can forecast the imbalances in real-time with the help of artificial intelligence and large quantities of data, making it easier to proactively handle future imbal-

5

The way forward

ances. The imbalances are foreseen to be reduced by 25 per cent and will hence reduce the frequency deviations significantly.

An appropriate funding scheme for R&D projects – NordGrid – where the Nordic TSOs are in lead, has been established in dialogue with Nordic Energy Research under the Nordic Council of Ministries. This funding scheme aims to improve the chances of overcoming innovation barriers, by motivating co-operation between TSOs, universities, R&D and industrial partners.

The R&D organizations of the Nordic TSOs (Nordic R&D group) are establishing a roadmap for Nordic R&D. The purpose is to tackle the challenges addressed in the report "Challenges and opportunities for the Nordic Power System" since many solutions are knowledge related – more insight is needed to evaluate the solutions.

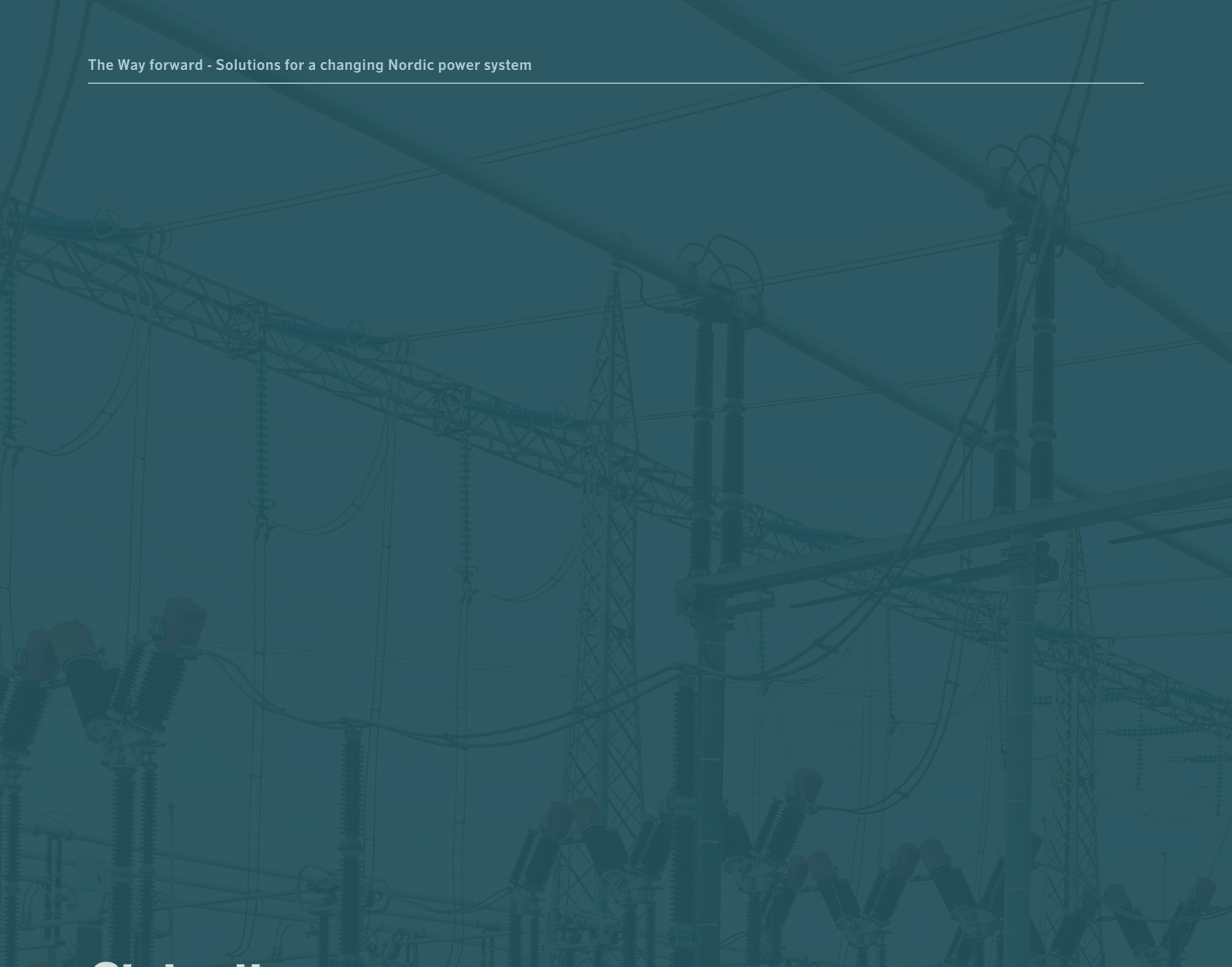
5.4 The Nordic TSO "way forward" – in a nutshell

IT development is paving the way forward; while a variety of common Nordic projects are framing the road with support stations and traffic signals. In the best of all worlds, the road just needs to be filled with producers, consumers and prosumers eager to contribute and benefit from a well-functioning Nordic power system.

In reality, however, much more needs to be done on the policy and regulatory side in order to ensure effective cooperation across the Nordic region. Preparing the Nordic power system to cope with the challenges ahead can only be secured in combining efforts on all three cooperation levels; energy policy, common system solutions and dedicated solutions.

This report is the first of its kind to present a system wide overview of the solutions the Nordic TSOs are working on in order to meet the future challenges for the Nordic power system. The Nordic TSOs' intention with this report is to support the cooperation on energy policy and to provide our stakeholders with a transparent insight to the Nordic TSOs' projects and activities - the report hence aims to increase transparency and enhance dialog between TSOs and our stakeholders.

The intention is to up-date this publication every second year and organize stakeholder events to discuss the progress. Up-dated roadmaps will be provided for these events. In addition, stakeholder engagement on dedicated solutions will continue, but our ambition is to lift discussions to a more Nordic (regional) level.



Statnett

Phone: +47 23 90 30 00
Fax: +47 23 90 30 01
E-mail: firmapost@statnett.no
statnett.no

ENERGINET

Phone: +45 70 10 22 44
Fax: +45 76 24 51 80
E-mail: info@energinet.dk
Energinet.dk

SVENSKA KRAFTNÄT
SWEDISH NATIONAL GRID

Phone: +46 10 475 80 00
Fax: +46 10 475 89 50
E-mail: registrator@svk.se
svk.se

FINGRID

Phone: +358 30 395 5000
E-mail: webmaster@fingrid.fi
Fingrid.fi

March 2018