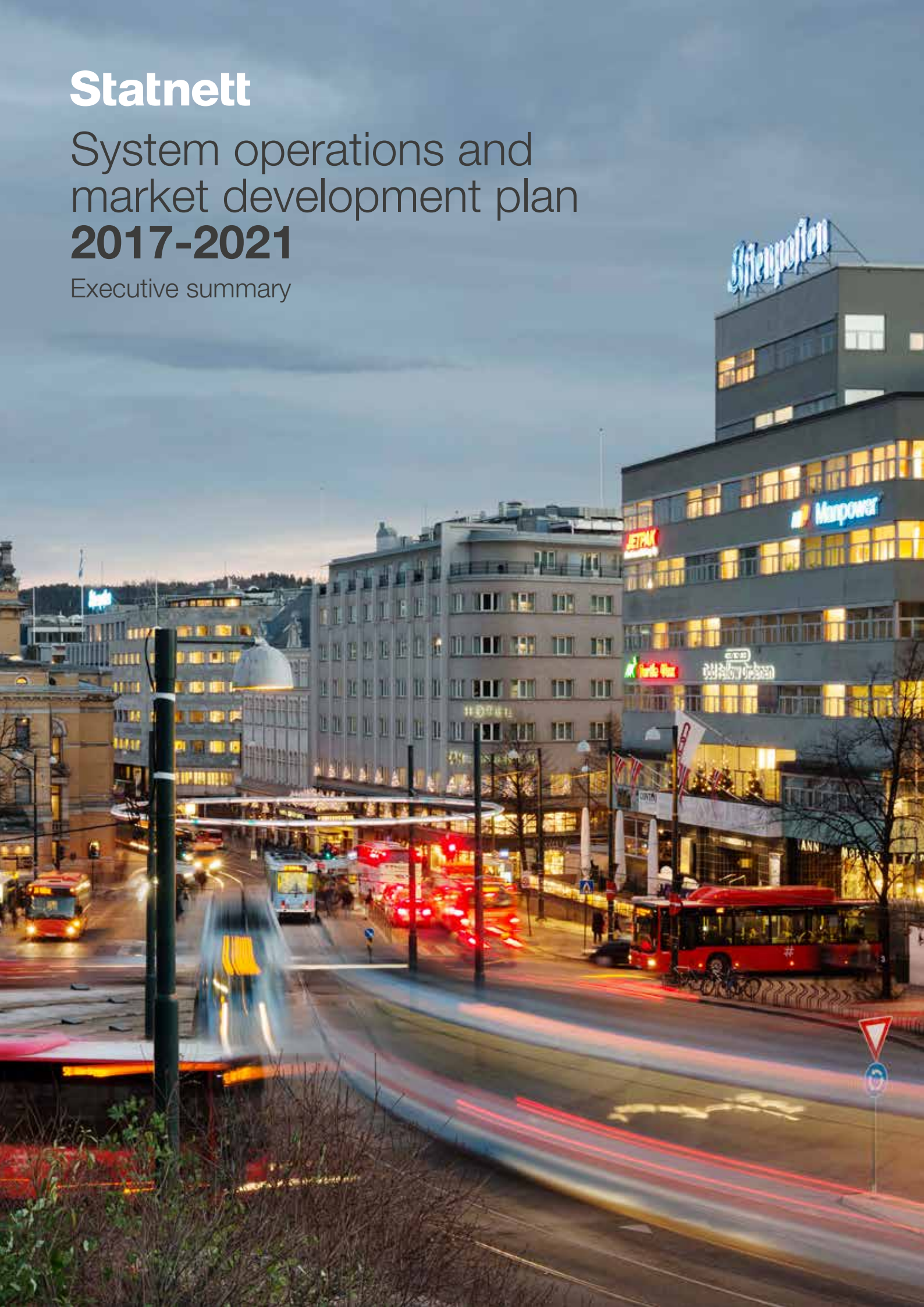
Statnett

System operations and market development plan **2017-2021**

Executive summary



Preface

The power system is a crucial infrastructure in modern societies. The dependency on electrical and digital services is increasing and reliable electricity supply is a prerequisite for well-functioning societies.

Through our role as transmission system operator, Statnett has the over-arching responsibility for a rational operation and development of the power system in Norway. Statnett shall ensure reliable access to electricity in the entire country and efficient utilisation of the power system.

The development of a more climate friendly and more closely integrated power system has significant implications for the operation of the power system. In a more integrated and complex power system, we need to adapt system operations and market solutions in order to utilise new opportunities and safeguard secure and efficient operation.

Statnett has developed an ambitious system operations and market development plan (SMUP) for the period 2017-2021. SMUP describes drivers affecting the operation of the power system, implications for the operation of the system, and a comprehensive plan for the development of market design and system operation measures. Through targeted efforts and prioritised measures, we will ensure control in a more complex power system, and enable better utilisation of resources and increased value creation.

Development and implementation of new solutions must largely be realised through Nordic cooperation. Yet, SMUP is not a mutually agreed Nordic plan. For coordinated plans at Nordic level, we refer to the report "Challenges and Oppertunities for the Nordic Power System" published in 2016, which will be followed by the "Nordic Solutions Report".

The development and implementation of new solutions depend on good and early interaction with stakeholders in the electricity sector. The comprehensive changes expected in the coming years call for common efforts of all parties involved. Norwegian as well as Nordic stakeholder should be willing to contribute to solutions that are an optimal compromise between their various concerns. Both the SMUP and the grid development plan (NUP) are important elements in the dialogue with the stakeholders in the electricity sector.

New solutions will affect the entire sector and Statnett wants to facilitate that information about the implications is available as early as possible for the stakeholders. At the same time, it is challenging to provide precise and firm plans at this stage due to the high degree of uncertainty. Significant changes require new and increased knowledge about the new power system. A comprehensive process to build Norwegian and Nordic knowledge about the future challenges is ongoing, which enables us to jointly implement the right solutions for the future.

Oslo 29.09.2017

Øivind Kristian Rue
Executive Vice President Market and Operations

Comprehensive changes require a common effort

The European power system is going through comprehensive changes with large-scale restructuring of the generation infrastructure and increased transmission capacity. The changes represent new opportunities for value creation for Norway, particularly in the form of increased benefits from utilisation of the flexibility of the hydro power system.

We also have to maintain security of supply in a power system with more variations in power flows and reduced margins in system operations. Changes in the distribution network caused by increased distributed power generation and demand response lead to additional challenges and opportunities.

In cooperation with stakeholders, we need to further develop system operations measures as well as new and improved market solutions. Therefore, we have developed a comprehensive and ambitious action plan for 2017-2021. The main areas of development are:

- Ensuring required functionalities in installations connected to the power system
- Further development of the energy markets and trade solutions
- Further development of ancillary and balancing services
- Improvement of decision support systems and increased automation in system- and market operations

Another key area is increased automation of system operations, which we will implement through a stepwise process. Towards 2020, we will focus on developing better decision support systems and automatic solutions for balancing and congestion management, As a prerequisite, we will also need to improve the quality of the power system data. Gradually, more intelligent and automatic solutions may contribute to increased efficiency and operational security within several aspects system operations, such as voltage control, outage coordination and planning, and capacity calculation.

The action plan implies changes that will affect the entire industry. Examples of areas where increased stakeholder engagement is required are:

- Ensuring availability and quality of power system data
- Adaptation to changes in functional requirements and new definitions of ancillary services, including prequalification for market participation
- Preparations for higher time resolution in energy and balancing markets
- Preparations for more frequent procurement of balancing services closer to the day of operation
- Preparations for new solutions to secure the stability of the power system
- Verification of delivery from assets providing ancillary and balancing services, and provision of information in order to improve security of supply and increase transparency
- Contributions to increased automation of central processes, initially in balancing
- Implementation of new communication solutions and standards

The implementation of the action plan requires significant efforts in many areas, and close and strong cooperation between Statnett, the other Nordic TSOs, and the other stakeholders in the electricity industry is required. In order to implement economically rational solutions over a relatively short time-span, and comply with the new European guidelines and regulations, coordination and cooperation are crucial. TSOs, regulators, and other stakeholders in the electricity industry must all contribute.

It is important to implement many of the planned measures before new interconnectors are commissioned in 2020 and 2021, as increased exchange capacity challenges system operations. If some of these measures are not implemented as planned or have less effect than expected, other temporary and less effective tools may be used to ensure operational security, at the cost of reduced benefits from the interconnectors.

We will facilitate transparent and more formalised processes for the stakeholder involvement through public consultations of new solutions. In this summary and in the extended version of the plan, we present the most important drivers for change and the most important opportunities and associated challenges, in addition to the main planned measures.

The system operator is obliged to act neutrally and non-discriminatory, and to the extent possible, apply measures based on market mechanisms.

Internationalisation characterises the development of the power system

European policies guide the development of energy markets

EU's internal market shall promote state neutral competition to the advantage of cooperation across the entire European economic area (EEA). Common, harmonised frameworks have been a key in the development towards an efficient internal energy market.

Since 2009, with the adoption of the Lisbon treaty, the EU has been provided with the authority to adopt rules and regulations for the energy sector in order to ensure the functioning of the energy market and security of supply in the EU, to promote energy efficiency and energy savings, and to develop renewable energy

Statnett's role as a transmission system operator
As transmission system operator, Statnett is responsible for the security of supply, efficient operation of the power system and necessary development of the Norwegian transmission grid. We must ensure reliable access to electricity in the entire country and facilitate value creation and good climate solutions.

We have the overall responsibility for operational planning and operation of the power system. Important tasks include maintaining the system balance at all times, and ensure that the power system has the necessary technical quality. We cooperate with relevant stakeholders on a national level in order to ensure that our responsibility is practiced in an economically efficient way.

Well-functioning energy markets are essential for system operations, and we are obliged to develop market solutions contributing to efficient utilisation and development of the power system. An important prerequisite is that the market design to a large extent reflects the physics of the power system.

The system operator shall act in a neutral and non-discriminatory way, and use market based measures to the greatest extent possible.

Statnett's responsibility as a transmission system operator is regulated by the Regulation of System Responsibility in the Power System under the Norwegian Energy Act. The Norwegian Regulator is now implementing changes in this Regulation, with the main goal is to provide a regulatory framework that ensures predictability and transparency, as well as stakeholder involvement, and also facilitates future EEA legal obligations. The changes are made in a two-step approach, with scheduled entry into force at 1.1.2018 and 1.1.2019 respectively.

sources and build infrastructure. The trend is that the EU increasingly uses regulations with a direct impact on the member states to achieve European targets.

The future electricity market will be characterised by increased cross-zonal capacity, common market solutions, more detailed regulations, and efficient cooperation.

In 2016-2017, the EU has adopted new regulations for the power markets, system operation, and connection to the power system. The regulations are comprehensive and affect all stakeholders in the power system. The regulations require for example increased coordination and cooperation among TSOs, facilitation of increased competition and electricity trade, and facilitation of increased participation by consumers and renewable energy generators in the energy markets.

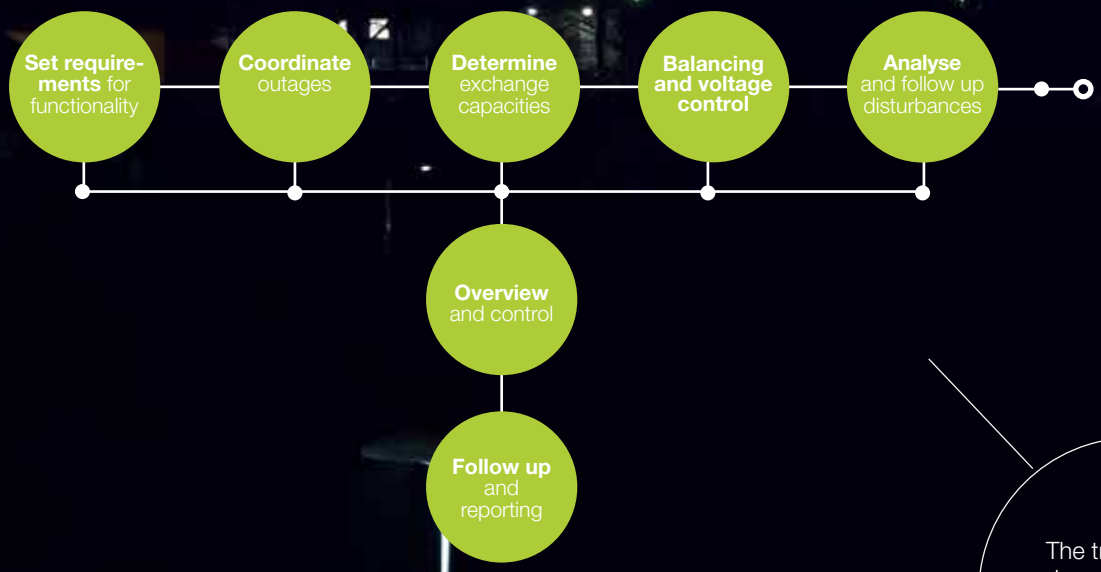
The regulations have resulted in a number of EU initiatives regarding cooperation at an international or pan-European level. Examples of this are the establishment of EU agencies with decision authority in a number of areas, such as ACER[1], and the establishment of Regional Security Coordinators.

The EU Commission's latest proposal for a new legislation on market design in energy markets is the "Clean Energy for all Europeans" from 2016. The Commission proposes more centralised solutions and seeks to develop and implement European energy policies through increased competencies for central entities. This implies changes in the distribution of roles and tasks from individual state level to international/European structures. For Norway's part, this raises the issue of EEA relevance of the regulations.

[1] Agency for the Cooperation of Energy Regulators

Ensure security of supply, facilitate an efficient power market and develop measures for system operations

The system operator's tasks in system operation



The transmission system operator plays an important role during extraordinary situations.

Figure 1
Illustration of the system operator's tasks in system operation.

	Network Code/Guideline	Scope
Market	Capacity Allocation and Congestion Management (CACM)	Requirements for day-ahead and intraday market, capacity calculation and power exchanges
	Forward Capacity Allocation (FCA)	Requirements for long term transmission rights
	Electricity Balancing (EB)	Requirements for balancing markets
System operation	System Operation (SO)	Requirements for maintaining operational security
	Emergency and restoration (ER)	Requirements applied in emergency or restoration
Connection	Requirements for generators (RfG)	Requirements for production units connected to the power system
	Demand connection code (DCC)	Requirements for consumption and network installations connected to the transmission grid
	High Voltage Direct Current Connections (HVDC)	Requirements for HVDC interconnectors and DC-linked production units

Table 1
Overview of Network Codes and Guidelines. For more information see www.entsoe.eu.

Good international solutions require substantial efforts

The Norwegian and Nordic electricity market is an integrated part of the common European electricity market. Common European framework, and common system operations and market solutions heavily influence the development in Norway and the Nordic area in general, and the framework for the execution of Statnett's responsibility as system operator in particular.

The Norwegian power system is different from the rest of Europe in terms of high capacity utilisation in the grid and power generation almost exclusively based on renewable energy sources with a high degree of flexibility. Therefore, Statnett takes active part in the European development work in order to ensure that the regulations safeguard Norwegian security of supply and the value of flexible resources, such as hydro power. In the development of European regulations, it is important to balance the need for common rules with Nordic and national considerations.

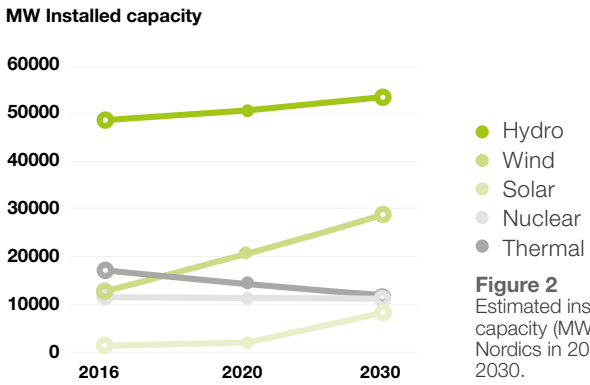


Figure 2
Estimated installed capacity (MW) in the Nordics in 2020 and 2030.

For Norway, we see the Nordic synchronous area as the natural starting point for increased international cooperation. A comprehensive effort is ongoing in order to adapt solutions and requirements to the new European guidelines and regulations, both on national and Nordic level. Norway and Sweden have currently a shared responsibility to maintain the system balance in the Nordic area. New common Nordic functions are now being implemented, including a Nordic office for operational planning, security analysis, outage planning coordination and transmission capacity calculation (the Nordic Regional Security Coordinator, RSC) and a Nordic company (eSett OY) for balance settlement of customers in Finland, Sweden and Norway.

Norway and Sweden have a common responsibility for balancing the Nordic power system. In order to meet future challenges and benefit from the European market developments, the Swedish TSO, Svenska Kraftnät, and Statnett are taking steps towards a new power system balancing concept. This implies enhanced cooperation between the two TSOs in developing necessary market solutions as well as other measures.

Tighter physical integration and changed production mix in Europe

The European countries have ambitious targets for reduction of greenhouse gas emissions. Hence, the European power system is currently going through a long and comprehensive transition process towards a power system based on renewable energy sources and new technologies.

The mix of generation capacity will change significantly even in the Nordic area. In 2015, the Norwegian government published a white paper stating that Norway wishes to become a part of the EU

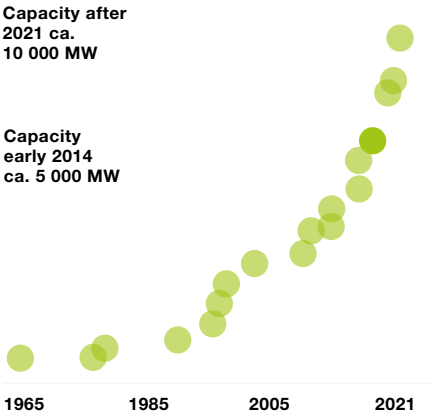


Figure 3
Expected increased interconnection capacity from the Nordic synchronous area from 2009 and to 2021.

Interconnector	Year	Capacity
Total installed before 2009		4500 MW
Storebælt	2010	600 MW
Estlink 2	2014	650 MW
SK4	2015	700 MW
NordBalt	2016	700 MW
NordLink	2020	1400 MW
North Sea Link	2021	1400 MW

Table 2
Overview of interconnectors from the Nordic syncronous area built between 2009 and new interconnectors with investment decision which are expected to be in operation within the next five years.

climate policy efforts and framework, and to contribute with emission cuts on par with the EU Member States.

We expect that the volume of wind power will increase substantially in the Nordic area. The growth in total nuclear power is expected to be moderate. Some nuclear capacity is phased out in Sweden, while new capacity is installed in Finland. In 2025, we expect a reduction of coal power plants in operation in the Nordics. Several plants will be decommissioned, and some converted to bio fuel.

The transmission capacity between the Nordics and the rest of Europe was about 7 000 MW at the end of 2016 (excluding capacity between Finland and Russia). When both NordLink and North Sea Link are fully operational in 2021, the capacity will increase to about 10 000 MW.

Tighter physical integration between the Nordics and the rest of Europe is an important contribution to increased socioeconomic benefits through better utilisation of resources. In addition, tighter system integration and market coupling with Europe are an insurance for dry years and periods with scarcity of generation resources in Norway.

We expect that increased interconnector capacity, and more renewable and variable power generation in the Nordics and in the rest of Europe will result in larger and more frequent changes in power generation and power flows than today. The consequences are most significant in the south of Norway, but will increasingly propagate further into other areas in the Nordic power system. This will increase the challenges related to power system operation.

High security of supply in the Norwegian power system

The security of supply in the Norwegian power system has shown a positive trend, even though it has been reduced in some periods with extreme weather conditions. The security of supply has been above 99.96 percent every year since 1996, which is considered very good. A security of supply level of 100 percent is not economically rational.

Comprehensive upgrade and expansion of the transmission grid requires efficient outage planning

Continued secure and efficient operation requires a robust transmission grid that is able to withstand higher loads and other flow patterns than today. Statnett has already started the construction of the next generation transmission grid that will ensure supply in exposed areas, and facilitate new interconnectors and new renewable power generation. The level of infrastructure investments will be high for the next years. For more information on Statnett's grid reinforcement projects, see our grid development plan (NUP).

A stronger transmission grid will increase security of supply in exposed areas

As a main rule, grid operation is based on the N-1 criterion, implying that reliable power supply is maintained even if the strongest component trips.

It is not economically efficient to maintain the N-1 criterion at all times, and we therefore employ additional criteria during system operation. According to Statnett's operational policy, we can accept conditions where single faults may lead to load shedding of up to one hour or a maximum of 200 MW, provided there are no planned or unplanned outages. During planned outages, we allow load shedding up to two hours or a maximum 500 MW.

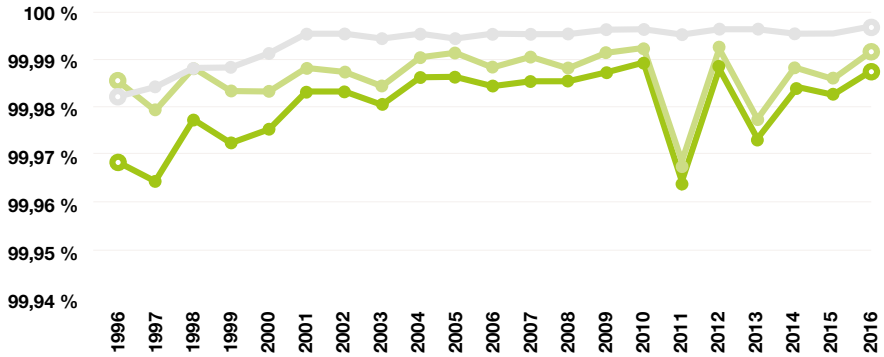


Figure 4
Development of security of supply from 1996 to 2016. Security of supply is calculated as (LE-ILE)/LE, where LE is delivered energy and ILE is energy not delivered. Source: NVE

The grid is operated at a higher risk in some areas. A strong transmission grid is necessary in order to maintain secure and efficient operations.

In today's transmission grid, it is not possible to maintain N-1 operation in all hours in all areas. Deviation from N-1 applies to situations where assets are out of service due to maintenance or upgrading and to periods where the grid is intact and the load is high. The consequences for operational security of deviating from N-1 operation vary between areas due to different switchgears and differences in the time it takes to correct potential faults. Examples of exposed areas are Lofoten/Vesterålen, Nord-Troms/Vest-Finnmark, Bergen, and Stavanger/Sandnes. Security of supply in eastern Norway is also vulnerable to prolonged faults in grid components.

Delivering secure operation and efficient use of capacity, even during grid upgrade and expansion periods
Comprehensive grid construction implies a substantial need to disconnect grid components. This is challenging as the grid capacity is highly utilised and results in periods of high flows on the available transmission capacity. Live-line work, meaning performing maintenance on energised equipment, is increasingly applied, but a large share of the construction work requires that the electrical components are de-energised.

Unavailability of grid components may lead to substantial costs for society in the form of increased market costs due to reduced trade capacity or reduced operational security. High socioeconomic costs associated with disconnection of installations imply high demands for efficient outage planning.

The system operator coordinates planned outages to ensure secure and efficient system operations, and seeks to base measures on socio-economic efficiency. We employ smart solutions, such as modifying grid topologies and use of system protection schemes, in order to increase the available transmission capacity. In some periods, it is not possible to carry out all planned outages without reduced transmission capacity and somewhat reduced security of supply.

Early notification of outage requests, good planning and close coordination are crucial in order to limit the consequences of outages. We experience that many outage requests are notified late and that plans are often changed. This could imply increased costs both for stakeholders and for society at large.

Well-coordinated outages limit the economic costs

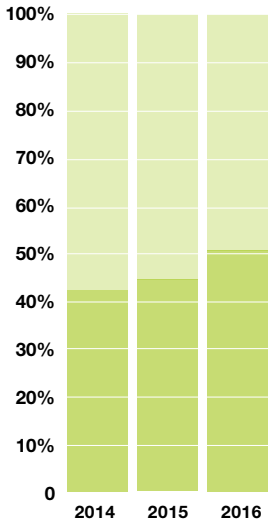


Figure 6
Number of requested outages, divided into requests recieved before and after deadline for the period 2014-2016.

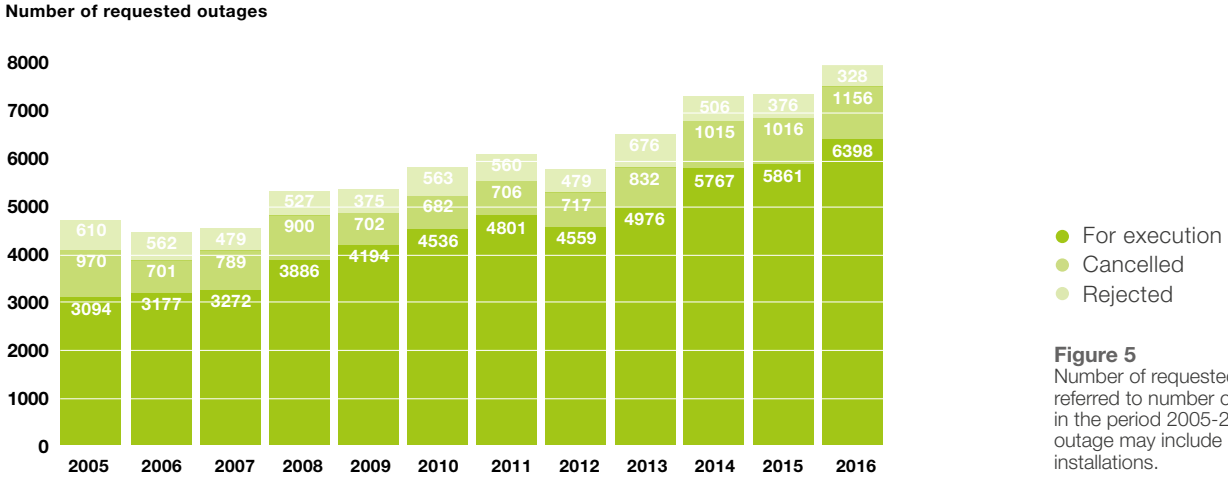


Figure 5
Number of requested outages, referred to number of installations, in the period 2005-2016. Each outage may include multiple installations.

Better utilisation of transmission capacity

Implementation of flow-based market algorithm

Lasting physical bottlenecks in the grid are managed most efficiently through bidding zone delineation. On a Nordic level, work is ongoing to develop a new methodology (flow-based market coupling) for the allocation of available grid capacity in the energy market, where the market clearing to a larger extent takes the physical characteristics of the grid into account. Flow-based market coupling will increase the consistency between market flows and physical flows, and result in more efficient utilisation of the physical grid capacity.

A common European grid model (Common Grid Model) and common rules for capacity calculation and congestion management between bidding zones are to be developed. The purpose is to both increase the operational security and to improve capacity utilisation. A common grid model is a prerequisite for the implementation of flow-based market coupling.

Better ramping regime for HVDC interconnections

Statnett is working to enable continuously change of flow on HVDC interconnections throughout the hour, in order to increase the volume that can be changed from one hour to the next. Today, the flow changed within 20 minutes around the hour shift, and must then be kept constant for the following 40 minutes. The background for this restriction is an agreement between the TSOs in Continental Europe, and the time resolution in the energy market. With the current restrictions and with the increase in interconnector capacity, it will take several hours to change flows from full imports to full exports. In order to maintain operational security, it will still be necessary to limit the volume and speed of flow changes. Primarily, we seek to realise increased ramping on HVDC interconnections by implementing finer time resolution in the energy markets, as this will facilitate continuous ramping without increased imbalances.Close monitoring and efficient management of grid interfaces and voltage conditions, especially in South Norway, are also necessary.

Moreover, we are working to improve the market algorithm in the day-ahead market, so that transmission losses on all HVDC interconnectors are taken into account. This will yield a more economically efficient trade solution.

Trading power capacity and flexibility

The strong Norwegian power balance in terms of capacity and the flexible hydropower capacity are the main motivations for foreign stakeholders to build interconnectors to the Nordics. Increased exchange capacity is expected to yield increased influence of European scarcity prices in energy markets, and in sum to yield an economic net benefit to Norway.

Common European markets for balancing services increase the opportunities to exploit flexibility cross-border. Estimates show that significant economic benefits may be realised by allocating some of the transmission capacity on the interconnectors NordLink and North Sea Link to exchange of balancing energy.

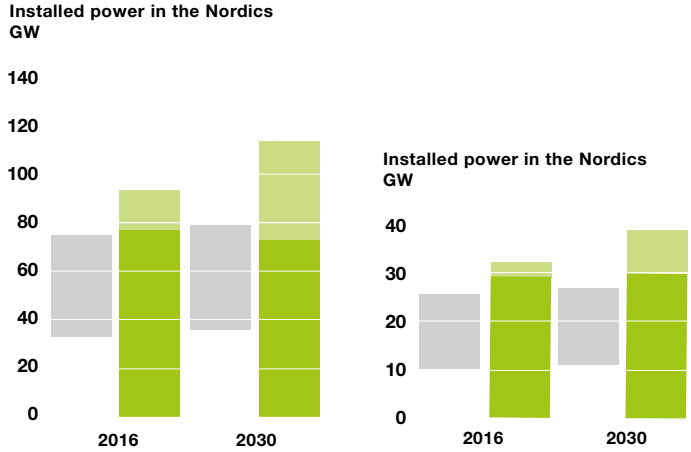
Through active advocacy and development of a feasible model for participation of interconnector capacity in capacity markets, the North Sea Link interconnector has been granted participation in the British capacity mechanism. This is a feasible trade model, which implies a remuneration for the Norwegian power capacity benefiting the British market.

The power capacity will be scarce in some areas

The generation capacity and the import capacity, together with demand flexibility, must be sufficient to balance energy over time and capacity in real-time.

In Norway, we have had a small number of periods where the energy situation in the whole or parts of the country has been labeled as tight[2] or strained[3]. Last time the energy situation was labeled tight was in Spring 2017. The spring weeks with the lowest reservoir

[2] The probability of rationing is considered to be below 20 percent, before the impact of any extraordinary measures are taken into consideration.
[3] The probability of rationing is considered to be between 20 and 50 percent before the impact of any extraordinary measures are taken into consideration.



- **Consumption**
- **Unregulated energy sources:** Small scale hydro, wind power, solar power
- **Regulated energy sources:** Reservoir hydro power, nuclear power and coal, gas and biofuel

Figure 7
Power balances in the Nordic countries and Norway in 2016 and 2030. The figure shows our estimates of installed capacity and largest / smallest consumption. Available power in real time will be less due to outages, bottlenecks, errors etc.

filling can be especially challenging. Implemented and planned grid reinforcements will reduce the risk of strained energy situations.

During the last couple of decades, the Norwegian and Nordic capacity balance have been satisfactory. The Nordic system has benefited from access to flexibility in the hydro power plants, and the peak load in large consumption areas has been secured by high availability of nuclear power capacity.

The capacity and energy situation is good, even though the energy situation has been tight in some periods

In the future, we expect capacity challenges in some parts of the Nordic market. Even if the total installed capacity in the Nordic market is larger than peak load, we cannot be sure that wind and solar generation is producing during peak demand hours. The capacity balance in Finland and the area consisting of South Sweden, East Norway, and Zealand, will be challenging. This area is likely to need new power generation and increased demand side response and/or increased import capacity. The rest of the Nordic market is not likely to experience capacity shortages.

The situation is more critical in many European countries, and several countries, such as Great Britain, have therefore implemented different forms of capacity mechanisms. As earlier mentioned, the North Sea Link has also been granted participation in the British capacity market.

The Nordic TSOs agree that we wish to keep the "energy only"-market model, supplied with strategic reserves where it is deemed necessary.

Balancing is increasingly challenging, and new solutions are required

The balance between generation and consumption in the power system must be maintained at all times. Well-functioning energy markets are central in balancing. It is crucial for efficient balancing in the planning phase that balance responsible parties trade themselves into balance in the markets.

Variations of generation within the hour, forecast errors and unforeseen events nevertheless require continuous monitoring of the balance and actions by the system operator to ensure momentary balance. To achieve this, the system operator acquires various types of balancing services (reserves). The reserves are used to alter generation or consumption on short notice.

Increased structural imbalances require changes in market design

The current market design with hourly time resolution causes imbalances between generation and consumption within the hour, so-called structural imbalances. Hourly time resolution in the energy market leads to changes in the production plans around the hour shift, in addition to changes in flows on interconnectors. Meanwhile, the changes in consumption occurs continuously throughout the hour. Large deviations occur primarily in hours with large changes in the generation, consumption and interconnector flows. Large imbalances often result in frequency deviations. Daily deviationsare illustrated in Figure 10 as a percentage of the day's 1440 minutes.

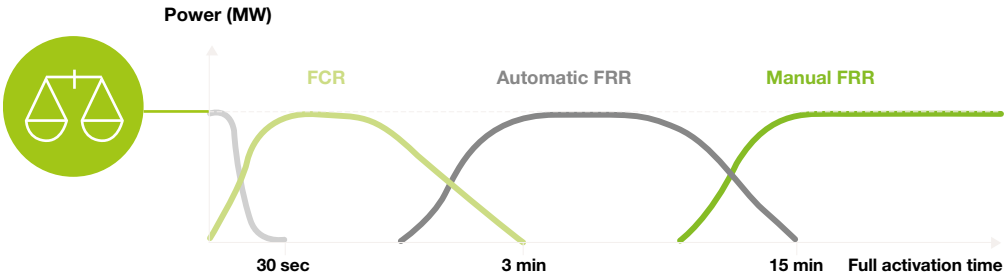


Figure 8
The relationship between response and activation time of the three types of reserves currently used to handle imbalances in the system. The light grey line illustrates the power system's natural inertia, which contributes to frequency regulation.

Deteriorating frequency quality indicates increased risk for the power supply

The frequency is an indicator of the momentary balance of the power system, and a change in frequency indicates an imbalance in the system and increased vulnerability to disruptions. If the frequency deviation becomes too large, consumption or production will be automatically disconnected. The Nordic synchronous area has a common frequency, which requires close Nordic cooperation in ensuring momentary balance.

Over time, the Nordic frequency quality has shown a negative trend, with more frequent and larger frequency deviations. The introduction of automatic frequency restoration reserves (aFRR) in 2013 has mitigated this trend.

The deterioration in the frequency quality is linked to increased imbalances, not least as a result of increased exchange capacity, but also due to the increased share of unregulated and unpredictable power generation.

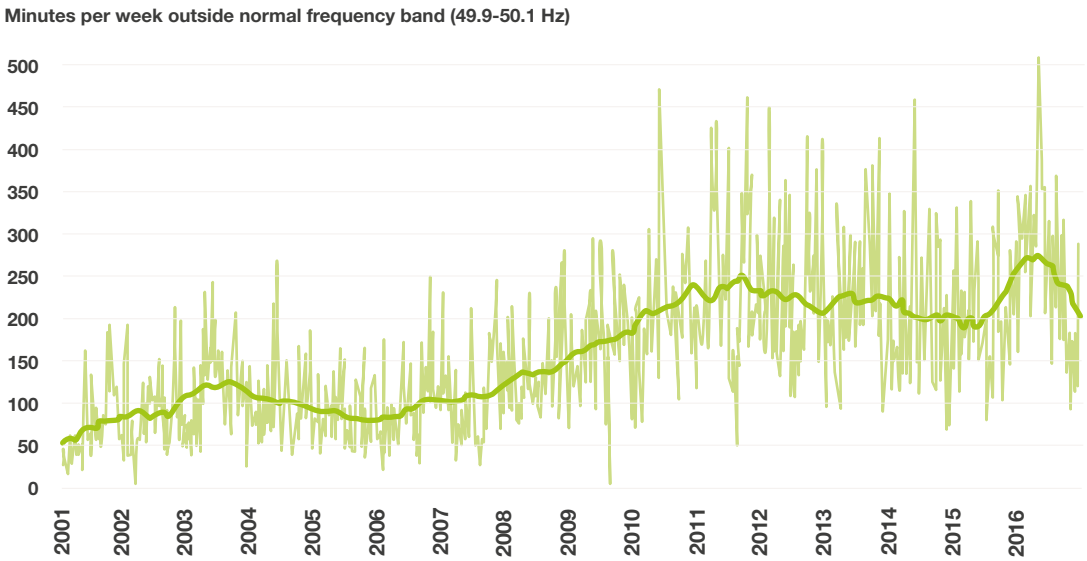


Figure 9
Frequency deviations in terms of minutes per week outside normal frequency band, 2001-2016.

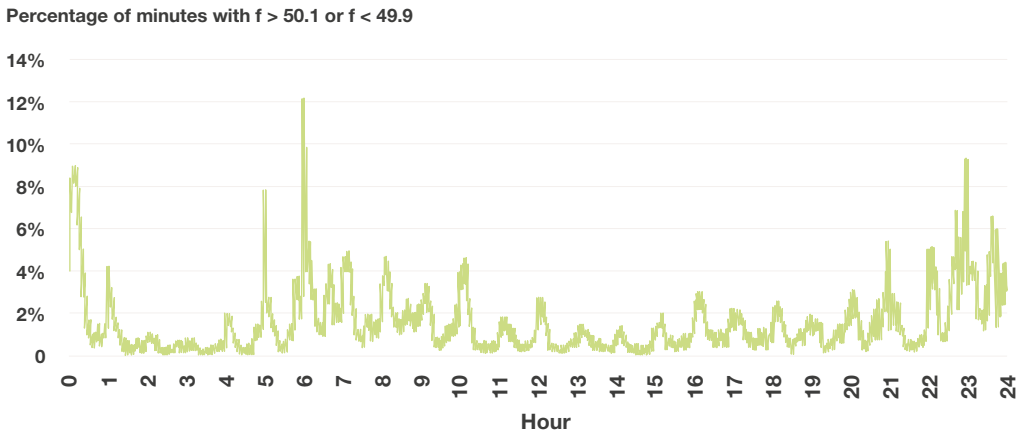
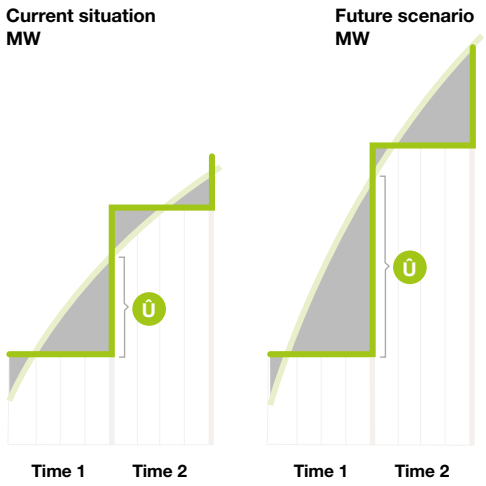


Figure 10
Percentage of minutes per day with frequency outside the normal band of 49.9-50.1 Hz, based on data from 2014-2016.



- Demand and exchange
- Generation schedule
- Imbalance
- Û Maximum imbalance

Figure 11
Illustration of imbalance between load and generation schedules within operating hours. The imbalances are increasing due to increased exchange capacity.

A market design with hourly time resolution yields increased structural imbalances

The significant increase in interconnector capacity between Norway and other areas results in larger and more frequent changes in power flows on the interconnectors. This will increase the structural imbalances significantly, unless mitigation measures are implemented. This is illustrated in Figure 11.

Finer time resolution in the energy markets is an efficient measure to reduce structural imbalances within the operating hour, especially within the most challenging hours with large changes in generation, consumption and interconnector flows. Finer time resolution in energy markets allows us to reduce structural imbalances in the planning phase, thus reducing the need for balancing actions in the operational phase. The implementation of finer time resolution in the energy and balancing markets in the Nordics is coordinated by an ongoing joint Nordic project. According to new EU regulations, the imbalance settlement period shall be reduced to 15 minutes by 2020.

We do not believe it is realistic to achieve fifteen minutes' time resolution in the spot market within the next few years. Finer time res-

olution requires consensus among multiple TSOs, regulators and power exchanges. However, we are working to implement finer time resolution in the intraday market, and to establish an additional auction after spot clearance with fifteen minutes' time resolution. Introduction of finer time resolution in cross border markets also gives market participants access to trade in flexibility. In particular, we see that offering power flexibility to the German fifteen-minute market can generate significant benefits.

Variable and unregulated generation yield increased imbalances

Actual wind power generation, and partly unregulated hydropower generation, may differ significantly from what was expected when the spot market was cleared. Imbalances due to inaccurate forecasts are expected to be largely corrected by increased trade in the intraday market. We are working on the development of a common European intraday market, XBID, which is scheduled to be launched around year-end 2017/early 2018 and will replace the current Elbas market.

Unregulated and unpredictable power generation yield larger stochastic imbalances

We still expect increased imbalances that the system operator must handle close to and in real time through the use of balancing services for up- and down-regulation of generation or consumption.

These reserves are partly secured through market-based procurement before clearing of the day-ahead market, to prevent that all flexible resources are sold in the energy markets. We procure balancing capacity for up-regulating bids for the winter season (RKOM). We frequently experience a need to extend the time period for such procurement as the season with a shortage of up-regulating bids gets longer. A market for balancing capacity for down-regulating bids is under consideration. We especially experience shortages of bids in the regulating power market in Eastern Norway, and we have therefore conducted a pilot where suppliers are allowed to offer aggregated flexibility. Based on positiv experiences, we will extend this pilot for the coming winter.

Efficient balancing requires accurate imbalance forecasts for the coming hours and associated tools to support operators in deciding which balancing energy bids to activate. We need to improve imbalance forecasting in the operators' decision support systems.

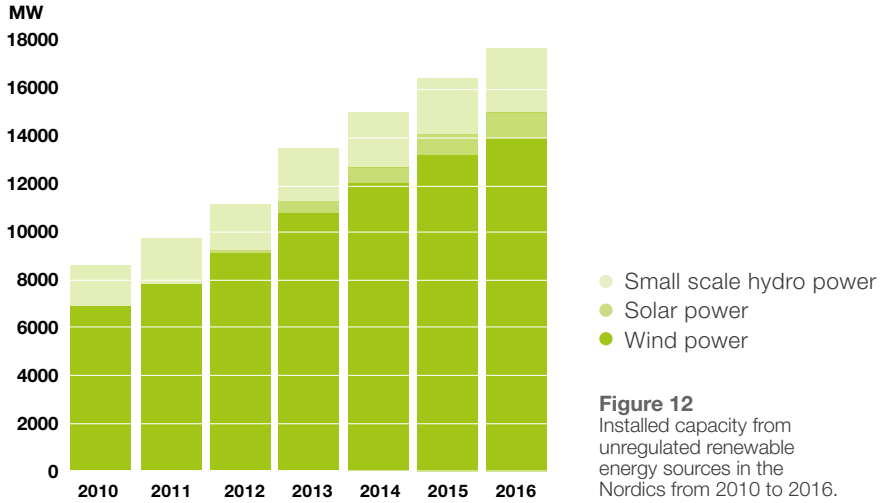


Figure 12
Installed capacity from unregulated renewable energy sources in the Nordics from 2010 to 2016.

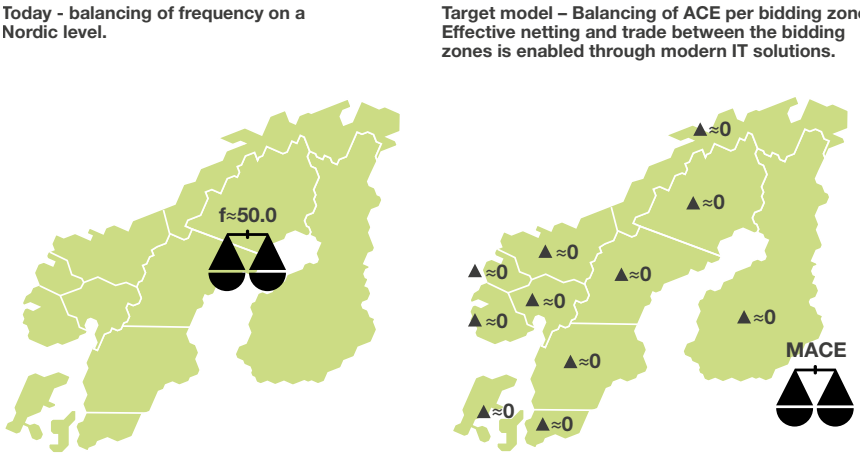


Figure 13
Illustration of current situation and target model for the new Nordic balancing concept with MACE.

Balancing per bidding zone provides better control and facilitate European market coupling

Today Statnett and the Swedish TSO, Svenska Kraftnät, together control the frequency in the Nordic power system. We have now together decided to move to a concept based on ACE (Area Control Error) on a bidding zone basis in order to have better control with the imbalances in the system. However, it is important to retain opportunities for imbalance netting and the use of the cheapest bids within the prevailing grid constraints. This will be obtained through the creation of a central platform through the MACE concept, "Modern ACE control".

System balancing based on ACE per bidding zone will make it easier to control bottlenecks and will contribute to sending the right price signals in the balancing markets. By giving better price signals, the balancing model will provide balancing service provides clearer guidance on the system's need for flexibility, including when and where the need arises. The balancing model will also facilitate trade of balancing services and regional/pan-European market coupling.

More efficient procurement and trading of balancing services

We are developing Nordic market solutions for automatic frequency restoration reserves (aFRR) and European market solutions for manual restoration reserves (mFRR). We are also working to establish efficient trading solutions for the exchange of automatic balancing services on the new interconnectors.

Overall, the Nordic power system has ample supply of flexibility, especially from hydropower plants. Still, balancing services are not always available where they are needed, because of bottlenecks in the grid. To ensure access to flexibility, balancing capacity must either be distributed in the grid or transmission capacity must be allocated for exchange of balancing energy. Traditionally, all transmission capacity has been allocated to the energy markets. However, we see that the marginal value of transmission capacity is sometimes greater for exchange of reserves than for energy trading. After a long process, we have gained approval to allow allocation of transmission capacity for exchange of balancing energy in situations where this is more socio-economically beneficial than energy trading. The Nordic market solution for automatic secondary reserves will enable allocation of transmission capacity between bidding zones when this is beneficial. This market will, indirectly, also result in increased demand for Norwegian flexibility and thus greater value creation.

We need efficient solutions to increase and utilise the flexibility from multiple sources. There is probably both an untapped flexibility potential on the demand side, as well as a potential to invest in greater power capacity by pumping water up into reservoirs during periods of low energy prices. We are considering opportunities for local utilisation of demand response. Among others, we will assess the potential flexibility in power consumption for water heating and electrical vehicle charging in our projections for future energy and power consumption in the Greater Oslo area. Improved forecasts can contribute to more optimal grid development.

Voltage control should be improved

Correct voltage level in the grid is essential to provide high quality of delivered energy, to limit grid losses, and to maintain life expectancy of grid components. The voltage quality has been improved by recent investments, but in the future, voltage control will be increasingly challenging due to faster and larger changes of power flows, and integration of variable power generation at lower grid levels. The voltage level varies between areas and is usually best handled by local measures.

Current settings on reactive components are often unfavorable for system operation

Generators in power plants, especially at lower voltage levels, contribute, along with individual grid components, to maintaining correct voltage levels. In Statnett's experience, power plants do not always respond as assumed, and many plants have voltage control settings that are unfavorable from a system perspective. Analyses of fault situations indicate missing functionality or malfunction in some power plants.

We are carrying out a systematic review of all of Statnett's reactive components, and will also collaborate with relevant stakeholders to review and clarify the need for adjustments for all voltage regulators on generators larger than 100 MVA. In addition, we will introduce solutions for verification of the actual response and deliveries from the generation assets. Together, this will provide increased operational security and more efficient operations that can reduce energy losses in the power system.

The stability of the power system will be challenged and new solutions are required

By stability, we mean the power system's ability to return to an acceptable steady state after a disturbance.

The frequency stability will be challenged in the future

The frequency stability is determined by the power system's inertia, and the response from frequency containment reserves (FCR). Large hydropower units and nuclear units are the main suppliers of stability in the power system. In the case of major operational disturbances, low inertia or little primary reserves in the system increase the risk of disconnection of consumption.

In the future, we expect less generation from hydropower plants in situations with low consumption. Along with reduced nuclear power generation, this will result in several hours of low stability margins primarily during night hours and in the summer period.

Today, the system operator procures sufficient volumes of primary reserves partly through required settings on generation units, and partly in a national market. So far, it has not been necessary to procure inertia explicitly.

There is an ongoing, joint Nordic effort to assess consequences and the need for new solutions. The conclusion so far is that there is a need for new measures to ensure sufficient inertia in the power system at all times. Better systems for monitoring the level of inertia and frequency reserves and potential dimensioning errors are also needed in order to continuously evaluate frequency stability margins. We are currently assessing and clarifying the different concepts to ensure secure operations in situations with low inertia. This is seen in conjunction with the design of new requirements for FCR.

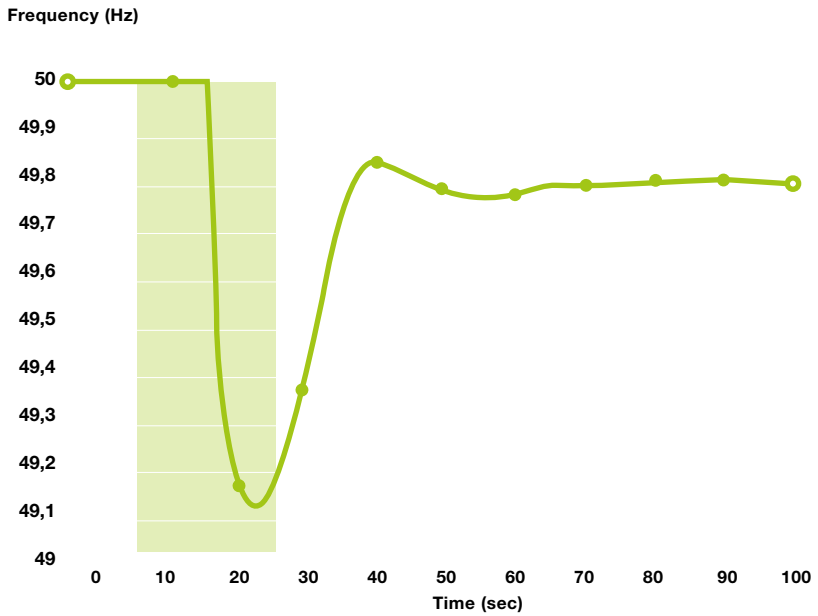


Figure 14
Illustration of drop in frequency, where the highlighted area indicates the time period where the system's inertia helps to reduce the frequency drop.

Stability margins are reduced if power plants do not respond as required

There is uncertainty as to whether the power system has the necessary properties to ensure operational security in all situations. Events and fault situations in the power system suggest malfunction or lack of functionality in equipment. Among others, island operation has resulted in breakdowns in several cases. The cause has been malfunctioning in some power plants in the area and/or incorrect settings on protection devices.

Unfavorable combinations of generator characteristics have caused undesirable oscillations in the power system. Especially the dynamic properties of waterways, turbines and hydraulics can cause such instability.

The ability to stabilise the system after a disturbance is challenged when a large share of generation comes from smaller, unregulated units like small-scale hydro and wind power. In the future, we expect that periods of low generation from large hydropower plants during the summer period will lead to reduced stability margins for handling both normal operation and incidents.

Increased shares of generation from smaller, unregulated sources, together with greater variability and increased complexity, increases the importance of larger power plants meeting functional requirements and responding as expected.

Increased complexity will be handled by improved decision support and automation

Efficient ICT-solutions are becoming increasingly important

System operations depend on well-functioning ICT systems throughout the value chain, from the calculation of water values and forecasts for generators, through trading on the power exchanges, to the planning and operation of the physical power system. Reliable platforms for metering, monitoring and exchange of information provide the opportunity to combine high efficiency with secure operation.

It will not be possible to operate the power system with today's decision support systems and relatively large degree of manual operations in the future. We will implement new technologies and more advanced ICT solutions. ICT development enables a smarter power system, with increased control, more and better analysis, better decision support and more automated solutions. Statnett's new operations control systm, e-Terra, in the form of the new operations control system, e-Terra, and the Norwegian-Swedish Fifty (TSO market system), form a good foundation for such a development. Meanwhile, new ICT solutions are developed within the European collaboration for new ICT solutions. A new European communications platform that will improve information security and the speed of electronic communication, has been developed. Furthermore, joint balancing markets will require joint ICT solutions.

More real-time information on key parameters for the power system, better information about the condition of components, monitoring of responses and deliveries, as well as more and better information about the external factors affecting the power system, can be exploited to improve visibility and control. Along with good decision support systems, this will enable fast and efficient decisions, increased automation and more efficient processes. In the future, we will be better able to predict conditions in the power system, enabling us to take more proactive steps and allowing for smaller operational margins without increasing the risk level.

New technologies increase the amount of available information and allow increased control at consumer level and in the power grid. The possibility to store and analyse large amounts of data and to exchange information more efficiently is increasing. For example, the rollout of advanced metering infrastructure can enable increased demand side flexibility.

We will develop more automated system operation in a step-wise process. Until 2020, we focus primarily on development of better decision support systems and automated solutions for balancing and congestion management, including improved basic data quality. We develop the current solution for automatic secondary reserve into an efficient Nordic market solution that takes bottlenecks into account. We are improving basic data quality and visualisation of system status reports and forecasts for operators. Furthermore, we are introducing electronic activation ordering of mFRR and changes in generation plans.

The likely next step is to introduce further automation of system operations, for example based on results from our “Smart Grid” R&D program. We see a potential for more intelligent and automated solutions that could contribute to increased efficiency and safer operation within several processes in system operations, such as voltage control, outage coordination and capacity calculation.

In the long term, we expect that operators to a greater extent will monitor the situation in the power system instead of performing manual operations, and mostly intervene in cases of deviations from normal operation. Such a development has to come about in collaboration between Statnett, other Nordic TSOs and the power industry in general.

Better power system data, plans and high quality forecasts are essential to achieve better decision support and increased automation. We therefore devote considerable attention and efforts to these areas.

Requirements to information security are increasing

It is important to secure critical ICT systems for system operation through emergency preparedness and measures related to information security. The measures should support availability and integrity within and between systems and across different actors in the power system, both nationally and internationally. Increased reliance on ICT and automation solutions also means increased demands for security and emergency preparedness.

Information security is a prioritised area in Statnett. We work systematically and comprehensively with risk management, ICT emergency preparedness and measures for information security. This work is carried out in close collaboration between Statnett and Norwegian authorities on information security issues.

DSO's role in the power system is changing

The role of grid owners at distribution level is changing and this will affect our role as system operator. The changes are driven by physical changes in the power system and the expectation of new possibilities for control and more efficient use of the power grid created by the combination of demand side response, generation at distribution level, and ICT-development, such as smart grids.

European and Norwegian regulations and framework for Distribution Systems Operators (DSOs) are under development. Statnett believes that DSOs should be given a more holistic responsibility for operation and development of the power system within their own area. At the same time, we see significant practical and principal issues that must be solved before DSOs are enabled to utilise flexibility in real time. Statnett considers it necessary to increase the effort on this topic by evaluating how new operational solutions can be integreted in the distribution network in the most appropriate way.

Distributed flexibility from consumption and generation can provide ancillary services to system operators both at transmission and distribution level and to the energy market. We seek a solution where the flexibility is used where it has its greatest the benefit. This requires development of solutions that ensure system security if multiple operators shall perform balancing within the same time frame.

Statnett believes that it would be appropriate to already now assign several operational tasks to DSOs that are ready for it. This requires agreements that describe how we can solve the practical cooperation in planning, operation and monitoring of the individual regional grid areas. Statnett will still exercise the system responsibility in distribution networks until there are alternatives that do not impair the security of supply or the need for neutrality and efficient markets.

At the same time, we must prepare for expected changes that will require adaptation and development of operational solutions and manage the interface towards grids at lower lotage level. We therefore launched an initiative on downstream system development the autumn of 2017. Framework for congestion management and use of distributed flexibility will be included in this work. The development must take place in dialogue with grid companies and within existing regulations and framework. Statnett has therefore invited the stakeholders to discuss challenges and the way forward for this topic.

New solutions for continued secure and efficient utilisation of the power system

Planned measures and new solutions will facilitate increased value creation, while at the same time enable us to handle new challenges. Prioritised measures are largely about facilitating high resource utilisation, including developments towards a common European market, while still ensuring sufficient control and safe operation in a much more integrated and complex power system.

For some time, we have been in a phase with substantial efforts devoted to develop new legislation and assessment of the impact of the transformation of the power system. Although this will still be key activities in the future, we are currently moving into an implementation phase in many areas.

We base decisions on socio-economic benefits

Statnett's mission is to ensure socio-economic efficient operation and development of the power system. Our choice of solutions and priorities is therefore based on socio-economic benefit assessments. Implementation of Nordic solutions are subject to increased Nordic socio-economic benefit. There will be no contradiction between the national and Nordic socio-ecomics as we work for solutions or agreements that ensure positive socio-economic profitability also for the individual countries.

In our value creation report we provide insight into how development of system operations and market solutions contribute to Norwegian and Nordic socio-economic value creation by presenting value estimates for several of our projects.

Statnett's profitability is subordinate to the objective of contributing to the greatest possible socio-economic benefit, and we are

neutral with regards to the distribution of costs and benefits among different stakeholders. The implementation of new solutions shall be cost-efficient. We expect an increase in system operation costs in the future, both as a result of an increased need for reserves and inertia and an increased alternative value of these services.

Common solutions will often be the most efficient solutions for the Nordic countries or Europe as a whole, and are often essential. Solutions are thus often decided in joint projects. Countries are different and do not always have common views or interests. Thus, compromises are often necessary.

Increased interconnector capacity must be managed in a controlled way

Efforts to prepare for the operation of approved new interconnectors are ongoing, with a view to be commissioned in 2020 and 2021. It is important to have implemented appropriate measures before the new interconnectors are put into operation, both to utilise the interconnectors in an efficient manner and to maintain secure operation. Many of these measures are essential to facilitate better resource utilisation and increased value creation. We will develop and implement efficient solutions for energy trade and exchange of balancing services, and establish agreements for operations, emergency preparedness and maintenance to ensure stable technical operation.

Increased exchange capacity will further challenge system operations already faced with increased imbalances. A number of measures must be in place in order to maintain safe operations while facilitating effective utilisation of new interconnectors. Measures must be taken to reduce imbalances in the planning phase, to manage imbalances and bottlenecks in operation, to ensure stability and to maintain control in a more complex power system. Increased exchange capacity must be handled through a controlled development, and must be coordinated with the implementation of efficient measures such as finer time resolution in the energy markets and increased use of automation in system operations.

However, the extent to which the measures will be sufficient is uncertain. If planned measures turn out to be insufficient or are not realised according to plan, other tools must be used which may imply less efficient use of the interconnectors. This may reduce the utilisation of existing and potential future interconnectors, and thereby reduce their benefits.

The plan is extensive, and many elements are uncertain

Several factors imply that the plan is uncertain. We are facing major changes in an increasingly more integrated and dynamic power system. This requires comprehensive analyses and assessments in order to build competence, and to be able to select the right solutions. In several areas, we are still in a phase with ongoing impact assessment and alternative analysis. New knowledge may imply changes to the plan.

Major changes caused by the new balancing concept in the Nordic synchronous area will have consequences for several ongoing projects. By 2017, we will establish a comprehensive plan for implementing the new concept, and some ongoing projects will be re-planned based on this.

This plan mostly meets European requirements and deadlines, but the European legislation is still under development and is only partially adopted in the EU. Previous experience with harmonisation and integration suggests that the processes often take longer than initially planned. Adjusted plans or requirements from the EU will affect the progress of the plan and the design of solutions.

For many of the measures, assessments are taking place in international projects, and decisions will largely be taken in cooperation with Svenska Kraftnät and the other Nordic or European TSOs. The various countries in the Nordics and Europe have different starting points, challenges and opportunities, and national interests. This means that processes can often be complex and take a long time. This also means that compromises will be necessary. In any case, Statnett will fulfill its national responsibility for security of supply. Although some of the presented measures will not be implemented as planned, the consequence will not be reduced operational security, but rather that other, less efficient solutions, will be implemented in the short term.

We seek a good dialogue with stakeholders and wish to provide good information about our action plans. Due to the high degree of uncertainty and the need to adjust plans on the background of the introduction of the new Nordic balancing concept, we aim to publish an updated version of our action plans during the first half of 2018.

Appendix

The figures illustrate current plans for the four different categories of measures. Measures are described in more detail in SMUP 2017-2021.

Action plan 2017-21: Ensure functionality in components connected to the power system

	Premises	2017	2018	2019	2020	2021
Develop proposal for Norwegian adaptation of European connection codes	Acc. EU-regulations (RfG)	National regulation Assess and recommend	Supplier adaptation			
Assess and publish guidelines for functionality of tecnical facilities	Acc. EU-regulations (RfG)	Assess and publish				
Improve quality of power system data		Complete,confirm	Update and assure data quality			
Improve voltage control		Document status quo, assess, implement				
Implement verication systems for supply of ancillary services		Assess, pilot	Stepwise impl.			

Action plan 2017-21: Further develop energy markets and trade solutions

	Premises	2017	2018	2019	2020	2021
Establish Nordic imbalance settlement (NSB)	International decision	Implement				
Evaluate Nordic imbalance settlement principles	International decision	Assess and recommend	Consult, implement			
Implement flow based market coupling in the Nordics	International decision acc.. EU regulations (CACM)	Assess and recommend	Implement			
Implement European intraday market	International decision acc. EU regulations (CACM)	Implement				
Implement finer time resolution in energy and balancing markets	International decision acc. EU regulations (EB)	Assess	Impl. (imbalance settlement, intraday, balancing)		Impl. day ahead	
Monitor and participate in relevant capacity markets		Monitor and influence development			Participate in relevant markets	
Implement implicit loss management on all Norwegian interconnectors	International decision	Assess	Implement		NL	NSL

- Assess consequences, needs and alternative solutions
- Evaluate and implement
- Specify and implement
- Deadlines according to European regulations
- Key milestones

Action plan 2017-21: Further develop ancillary and balancing services

	Premises	2017	2018	2019	2020	2021
Implement balancing per bidding zone in the Nordics (MACE)	International decision	Plan, design, implement stepwise				
Establish Nordic goals for frequency quality and dimensioning of automatic reserves	International decision acc. EU regulations (SO)	Assess	SOA			
Implement new Nordic technical requirements for FCR	International decision	Assess	Develop design	Implement stepwise		
Develop Nordic solution for procurement of FCR and intertia	International decision	Assess, implement stepwise				
Develop European balancing activation market for FRR	International decision acc. EU regulations (EB)	Design, develop solutions			Implement stepwise	
Implement standard products for FRR	International decision acc. EU regulations (EB)	Develop proposal	Consult	Implement		
Establish Nordic Balancing capacity market for secondary reserves (aFRR)	International decision	Tender, implementation				
Establish Nordic Balancing energy market for secondary reserves (aFRR)	International decision	Plan, design	Implement			
Implement bid volume per 15 min in the Nordic regulating power market (mFRR)		Implement				
Implement solution for procurement of mFRR capacity for down regulation	International decision	Assess and implement				
Implement prequalification for balancing service providers	Acc. EU regulations (SO, EB)	Develop terms and conditions, and process	Implement stepwise			
Implement procurement of balancing capacity closer to real time (D-2)	International decision	Stepwise impl.		aFRR mFRR		FCR
Implement coordinated procurement of balancing capaity	International decision			Assess		
Facilitate increased marked participation from demand side response	Partly international decision	Pilot, assess	Implement stepwise			

● Assess consequences, needs and alternative solutions ● Evaluate and implement ● Specify and implement — Deadlines according to European regulations — Key milestones

Action plan 2017-21: Further develop decision support systems and automation

	Premises	2017	2018	2019	2020	2021
Implement electronic ordering of activation of mFRR and changes in generation plans		Pilot, evaluation				
		Stepwise implementation				
Develop solutions for better forecasts	Nordic data					
		Develop and implement solution				
Develop web portal for power system data (Fosweb)						
		Imp. stepwise	Continuously develop new functionality			
Develop common market system, Statnett – Svenska kraftnät (Fifty)	International decision	Stepwise implementation				
		Common development				
Establish common Nordic and European grid model (CGM)	International decision acc. EU-regulations (CACM, SO)					
		Complete model	Implement			
Implement new communication standard between control centers (ICCP)						
		Stepwise implementation				
Implement new communication plattform for market system (MADES)						
		Assess and stepwise implementation				

- Assess consequences, needs and alternative solutions
- Evaluate and implement
- Specify and implement
- Deadlines according to European regulations
- Key milestones

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