NOVEMBER 2017

SYSTEM DEVELOPMENT PLAN 2018–2027

Towards a flexible power system in a changing world.

SVENSKA KRAFTNÄT

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Our society is dependent on electricity. Svenska kraftnät is responsible for ensuring that Sweden has a safe, environmentally sound and cost-effective transmission system for electricity – today and in the future. We achieve this in the short term by monitoring the electrical system around the clock, and in the long term by building new power lines to meet tomorrow's electricity needs.

Illustratrations and maps are created by Svenska kraftnät.

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FOREWORD

The power system is now in a phase characterised by rapid and comprehensive changes. An increasing share of weather-dependent, renewable electricity generation, distributed generation and rapid changes in consumption patterns entail entirely new requirements that the power system must be able to meet.

In 2013, Svenska kraftnät published the Perspective Plan 2025 which in 2015 was followed by the Network Development Plan 2016-2025. These reflected a need for more long-term planning documents for the development of the Swedish transmission grid. The rapid and extensive changes that now characterise the power system's development, however, require a holistic perspective. In light of this, we have prepared the System Development Plan 2018-2027. The System Development Plan builds further on the Network Development Plan 2016-2025, but broadens the perspective to comprise, in addition to grid development, issues related to operating conditions and market structure.

With this first version of the System Development Plan, Svenska kraftnät wants to present both how we view the challenges that the power system is facing, and also point to possible solutions. The solutions are in various phases of development and the level of concrete detail therefore differs. In many respects, this System Development Plan is therefore the beginning of a continued effort where there is a need to further develop the solutions.

The System Development Plan aims to both set out the direction of the continued work internally at Svenska kraftnät, and also form an important part of our external dialogue. Here, we see a need for in-depth cooperation with industry actors and other stakeholders. The main external target groups for the System Development Plan are our large transmission grid customers and balance-responsible parties, the main service providers for Svenska kraftnät, as well as authorities and ministries.

The System Development Plan considers different time perspectives in different sections. Considering the long implementation times needed for various measures, we must take into account the power system's long-term development and hence the plan largely has a perspective extending to 2040. At the same time, the rapid development of the power system limits the possibility of making long-term plans for some areas and concrete measures are needed in more near-term plans. As in the previous Network Development Plan, the grid development section has a ten-year planning horizon for the known grid investments.

We are now looking forward to meeting in a creative dialogue on the System Development Plan and our common challenges within a Nordic power system that is undergoing its largest change in 20 years.

Sundbyberg, November 30, 2017

Ulla Sandborgh
Director General and CEO, Svenska kraftnät

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1. INTRODUCTION

1.1 Background

The Swedish power system is facing major changes towards 2040. The Energy Agreement that was reached in Sweden will lead to a continuing transition to renewable energy and, as a part of this transition, an entirely new power system is emerging. While on the surface this transition may look like one generation type being replaced by another, it has significantly deeper consequences from a power system perspective. Extensive measures will thereby be required in many areas in order to maintain a secure supply of electricity so that the expectations of all customers can be met.

By preparing a plan for system development, Svenska kraftnät wishes to make it clear that focus is on the future development of the entire power system and not just the transmission grid. The System Development Plan therefore comprises a combination of measures that involve improvement of the system's stability and market changes, as well as, of course, grid development. The transfer capacity of the grid is in many respects absolutely crucial for the operation of the power system and for providing an adequate level of security of supply.

The challenges resulting from the major transition of the power system mean that many different measures must first be evaluated and then implemented. The participants in the power system are affected in different ways, depending on which measures are chosen. In evaluating alternative measures, the needs of the overall power system will be crucial for the selection of the most effective solution. Different solutions are also needed over time, with a simpler or more quickly implementable solution being applied first, to then be supplemented by a more extensive change in line with the changing power system.

New or adjusted ancillary services are an important part of the solution since they provide the possibility of using, on market-based conditions, resources that already exist or that can be supplied by commercial actors. There will likely be a need to weigh the overall costs for the system for these services against those for other measures in order to find the most optimal solution in the long term.

The design of the market structure is another area where changes must take place. Today's model is in several areas not adapted to an electricity market with a large share of intermittent generation. A shorter imbalance settlement period, for example, could facilitate the work of the operations department by reducing the imbalances caused by the market. New transmission lines, or other measures, are also needed to provide the market with access to sufficient capacity to both handle day-ahead trading and at the same time offer sufficient capacity for trading ancillary services.

The System Development Plan shows Svenska kraftnät's focus and plan for future work in all of these areas. At present, there are no concrete solutions or proposals for change for all of the challenges described. In many cases, the serious consequences are also many years into the future; Svenska kraftnät has nonetheless chosen to take a comprehensive approach and indicate the development needs that exist.

Development efforts in the IT area are necessary to enable many of the solutions identified in the System Development Plan. These measures are not described in the System Development Plan, but will require significant effort and attention for many years to come.

1.2 Structure of the System Development Plan

1.2.1 Chapter 2-4 describe the context

Chapter 2: The System Development Plan begins with a description of the most fundamental objective of the power system: to ensure that electricity consumers have access to the electricity they need. This is at the core of the concept of security of supply and is a responsibility that is shared between many different actors and roles. The aim here is to clarify Svenska kratnät's responsibility and role, and also what lies outside of these. Creating a common understanding of these concepts is fundamental for enabling the power system to be developed effectively and meet future challenges.

Chapter 3: This chapter contains a description of the external framework and prerequisites that Svenska kraftnät works within, which are also of major significance to the on-going transition in the power system. Political ambitions, formulated through the various climate targets, are increasingly driving change in the power system through a direct impact on generation and consumption. Since both the physical power system and the electricity market in Sweden are highly integrated within the Nordic region and the rest of Europe, Svenska kraftnät does not have full freedom to unilaterally decide on all measures that are needed to meet the forthcoming challenges. Many of the regulations and laws that control how the power system will be operated and developed, as well as how the trade in electricity should take place, are now decided within the EU. There, the European Commission is currently working on further harmonisation of the rules within the Union.

Chapter 4: The System Development Plan also contains an analysis of how the power system may change towards 2040. The objective of this chapter is to identify the challenges and consequences that various development trends and driving forces have for the power system. Svenska kraftnät has prepared a reference scenario for how the power system may change towards 2040. These analyses do not, however, aim to identify and quantify the benefit of new connections. The future will most likely not look like the scenario shown, but the underlying trends are clear. The primary results and challenges for the power system that the analyses highlight are therefore important to include in the future system development.

1.2.2 Chapters 5-9 describe challenges and solutions

Based on the description of roles and frameworks, as well as the power system's future development, a deeper description of the system challenges and solutions follows in these chapters. Here, the System Development Plan addresses the concrete measures that Svenska kraftnät intends to work with during the upcoming ten-year period.

Chapter 5: In all situations, the power system needs to have sufficient ability to handle the very first period of time after a major disturbance, while maintaining system stability. Therefore, the challenges and measures related to ensuring adequate stability in the power system are described first. One example of such a challenge is the decrease of inertia that results from the decommissioning of nuclear power plants, since this would reduce the possibility to be able to maintain the frequency in the power system.

Chapter 6: In any given instance, there need to be sufficient means to restore and keep the system in balance, for which it is crucial that there is access to different reserves and ancillary services. The conditions for this are affected by various market solutions since they lay the foundation for a good balance between electricity generation and electricity consumption. To be able to meet the challenges of balancing, a combination of different kinds of measures is needed.

Chapter 7: How the electricity market is structured also affects how well the electricity grid is utilised and thereby also the need for reinforcements and expansions. Regulations also have a major impact on the incentives for various actors to establish or discontinue electricity generation. In particular, the economic conditions for generation which is only needed at times of peak consumption will strongly affect Svenska kraftnät's handling of balancing in the future. Several adjustments are needed to provide the right conditions for dealing with these challenges. There is also a strong connection to the on-going development in the European market regulation.

Chapter 8: This description of how the grid will be developed focuses on the upcoming ten-year period 2018-2027. This chapter also mainly contains measures linked to the legal obligation to connect new electricity generation and electricity consumption. A detailed list of the major projects expected in the coming ten years is in the appendix "10-year network investment plan". In the grid development section, the fact is also discussed that Svenska kraftnät's investments are strongly affected by the need to refurbish the ageing transmission grid. Major resources therefore need to be allocated to reinvestments so that personal safety and security of supply in the existing grid are not threatened. The need for renewal in combination with the on-going development of the transmission grid will also present a challenge for grid operations and the electricity market in the form of an increased need for planned outages.

Chapter 9: This chapter describes the financial consequences of the investment activities in the coming ten-year period.

1.3 Explanation of terms

The following is an explanation of some key terms as they are used in the System Development Plan.

Active power: the part of the power where voltage and current are in phase. The power can perform work.

Adequacy: every subsystem (the generation units and the various grids) in the power system has adequate capacity to meet the users' needs for energy and power.

Ancillary services: collective term for functions that are fundamental for maintaining a stable power system and thereby also for security of supply. Examples of such system services are frequency control, voltage regulation, various kinds of reserves and, with its increasing importance, also inertia.

1. Balancing services: balancing energy or balancing capacity or both.

  - **Balancing energy:** energy that is used by Transmission System Operators (TSO) to perform balancing that is provided by a balancing service provider (BSP).
  - **Balancing capacity:** a volume of reserve capacity that a Balancing Service Provider (BSP) has agreed to hold and in respect to which the BSP has agreed to submit bids for a corresponding volume of balancing energy to the Transmission System Operator (TSO) for the duration of the contract.

- **FRR, Frequency Restoration Reserves:** active power reserves with the purpose to restore system frequency to the nominal frequency and, for a synchronous area consisting of more than one LFC area, to restore power balance to the scheduled value.
  - **aFRR:** FRR with automatic activation. Also known as secondary frequency control or secondary control.
  - **mFRR:** FRR with manual activation. Also known as tertiary frequency control or tertiary control.
- **RR, Replacement Reserves:** active power reserves able to re-store or support the required level of Frequency Restoration Reserves (FRR) to be prepared for additional system imbalances. RR is a balancing service that does not exist in the Nordic market today.

2. Frequency control:

- **FCR, Frequency Containment Reserves:** active power reserves for containment of frequency fluctuations. Also known as primary frequency control or primary control.
  - **FCR-N:** FCR that is activated upon a frequency deviation within ±0.1 Hz.
  - **FCR-D:** FCR that is activated upon a frequency below 49.9 Hz and above 50.1 Hz.
- **FFR, Fast Frequency Response:** a system service with the purpose of managing rapid imbalances to counteract the impact of reduced inertia in the system. FFR responds faster than FCR and is a system service that does not exist in the Nordic market today.

3. Voltage regulation: the regulation of the voltage that the synchronously connected generators contribute to through their generation or consumption of reactive power, both in normal operation and upon disturbances.

4. Inertia: inertial response is the property of the rotating masses that are synchronously connected to the power system. This creates inertia, which quantitatively can be described as the rotating kinetic energy at a nominal frequency and counteracts frequency changes in the power system.

Area Control Error, ACE: the sum of an area's imbalance, which is the difference between the measured power interchange and the control value for a specific LFC area or LFC block and frequency control error.

Balance responsible party: according to the Electricity Act, an electricity supplier may only supply electricity at connection points where a party has assumed the financial responsibility for the national power system being supplied as much electricity as is withdrawn at the connection point. This party is called a balance-responsible party (BRP).

Balancing: all actions and processes, within all time frames, through which the Transmission System Operator (TSO) ensures that the system frequency is kept within a pre-defined stability range and that there are necessary reserves.

Balancing market: the combination of institutional, commercial and operational arrangements that establish a market-based management of balancing.

- The Nordic regulating power market: a part of the broader concept of the Balancing Market where mFRR energy bids are submitted and activated.

Balancing Service Provider, BSP: a market participant that provides balancing services to the system operator.

Clean Energy Package, CEP: a number of legislative proposals from the European Commission presented in autumn 2016, comprising energy efficiency, renewable energy, the structure of electricity markets, secure electricity supply and rules for the governance of the Energy Union.

Cut 1, 2 and 4: the Swedish power system is split into four bidding zones from north to south, which creates three internal borders. In Swedish, these borders are given a specific name ("Snitt"), which is translated in this report as "Cut".

- Cut 1 is the border between SE1 and SE2,
- Cut 2 the border between SE2 and SE3,
- Cut 4 the border between SE3 and SE4.

Demand response: the change or shift of electricity consumption within a certain time frame as a result of high or low electricity prices.

Dimensioning incident: the largest expected disturbance that can

PHOTO: TOMAS ÄRLEMO

occur, which the system is dimensioned to manage.

Distribution System Operator, DSO: a future role that exercises a subsystem responsibility for regional or local grids.

Energy Agreement ("Energiöverenskommelsen"): The Energy Agreement is a political agreement between five of the parties represented in the Swedish Parliament which has a goal for 100 percent of Sweden's electricity generation to come from renewable sources by 2040.

Energy balance: the difference between produced and consumed electric power for a certain area during a certain period. A positive energy balance for an area means that total generation is greater than total consumption during the period concerned, and that the net export of electric power during the period is thereby positive. For the Nordic countries, the annual energy balance is often expressed in terawatt hours (TWh).

Energy Commission ("Energikommissionen"): a politically appointed commission with representatives from the Swedish Parliament led by the Minister for Energy. The Commission's goal is to reach a broad political agreement on Sweden's long-term energy policy.

European Agency for the Cooperation of Energy Regulators, ACER: cooperative organisation for the national energy regulators in the EU.

European Network of Transmission System Operators for Electricity, ENTSO-E: the European cooperative organisation for national transmission system operators.

Frequency stability: the power system's ability to keep the frequency stable in normal operation and in the event of disturbances.

Generation adequacy: there is sufficient power available in the system within a certain geographical area to meet consumption, including imports, exports and losses.

Grid owner: the companies that own and manage the various grids that together form the Swedish power grid. This defines everything from the local grid companies that connect household customers all the way to the transmission grid that is owned by the state and managed by Svenska kraftnät.

Guideline on Capacity Allocation and Congestion management, GL CACM: the EU Commission's legally binding regulations related to capacity allocation and congestion management.

Guideline on Electricity Balancing, GL EB: the EU Commission's legally binding regulations related to balancing.

Guideline on System Operation, GL SO: the EU Commission's legally binding regulations related to system operation.

Instantaneous power balance: that power generation and consumption are equal at a given moment and that the frequency thereby does not change.

LFC area (Load-Frequency Control Area): a part of a synchronous area or an entire synchronous area, physically limited by points of measurement at interconnectors to other LFC Areas, operated by one or more Transmission System Operators.

LFC block (Load-Frequency Control Block): a part of a synchronous area or an entire synchronous area, physically limited by points of measurement at interconnectors to other LFC Blocks, consisting of one or more LFC Areas, operated by one or more Transmission System Operators.

MACE control: use of modern IT solutions, optimisations, automatic reserves and available transfer capacity to regulate ACE.

N-1 criterion: the power system must be able to handle the outage of a component and have the ability to adapt to the new operating situation and at the same time maintain the area's security of supply.

National Regulatory Authority: the various grid companies in the power system are regulated by a specific authority. In Sweden, this role is held by the Swedish Energy Markets Inspectorate.

Network codes: EU regulations with detailed, legally binding rules in the form of network codes and EU Commission guidelines. The network codes are developed at a European level and apply to electricity markets, connections to the grid and system operation.

Operational reliability: the ability of each part (generation plants and the various grids) in the power system to maintain reliable operation, to maintain a normal status or to quickly return to the normal status, as defined by set criteria.

Primary control: see "FCR" under the term "Ancillary services".

Power producer: the owner of a facility for electricity generation. This thereby comprises everything from nuclear power, hydroelectric power and wind power, as well as smaller facilities, such as solar panels. Regardless of the facility's size, it must fulfil certain requirements to be connected to the power system.

Reactive power: the part of the power where voltage and current are not in phase - the power does not perform any work.

Reliability: the power system's capacity to maintain the stability and to be able to withstand disturbances.

Rotor-angle stability: the ability of synchronously-connected generators to remain in synchronous operation, i.e. the ability to keep the rotor angle difference between generators small in both normal operation and in the event of disturbances.

Secondary control: see "aFRR" under the term "Ancillary services".

Security of supply: the ability of the entire power system to maintain the supply of electricity to end consumers.

System responsibility: Svenska kraftnät has the system responsibility for electricity in Sweden. This will lead to ensuring, through its own efforts and coordination of others' efforts, that the reliability in the power system can be maintained at the same time as optimising costs for system operation. This responsibility includes maintaining the balance between generation and consumption of electricity at the operational level.

Ten-Year Network Development Plan, TYNDP: the ten-year plan for the development of the European network, which is prepared by ENTSO-E every two years.

Tertiary control: see "mFRR" under the term "Ancillary services".

Transmission system operator (TSO): the function through which Svenska kraftnät exercises its system responsibility.

Voltage stability: the power system's ability to keep an acceptable voltage level, as defined by set criteria, in all nodes under normal operation and in the event of disturbances.

2. ROLES AND DUTIES IN THE POWER SYSTEM

SUMMARY

Succeeding in the on-going transformation of the power system requires a clear and appropriate allocation of roles, powers and duties. Svenska kraftnät is of the opinion is that at present, the roles and duties of the various actors in the electricity market are not clearly defined, and that as a result security of supply could be compromised in the longer term.

- Svenska kraftnät has two roles, as grid owner and as system responsible authority.
  - As grid owner, Svenska kraftnät is responsible for sufficient trans-fer capacity being available to meet demand's transmission needs, and for the transmission grid being robust enough to handle different incidents and disturbances. Svenska kraftnät is not responsible for grid capacity and robustness in local and regional grids.
  - As system responsible authority, Svenska kraftnät is responsible, through its own efforts and the coordination of others' efforts, for ensuring the reliability of the power system. In practice, the system responsibility includes controlling, monitoring and identifying the needs of the factors that affect the power system's stability and balancing. Svenska kraftnät is not solely responsible for the balancing in the interconnected Nordic power system. The responsibility for balancing the Nordic power system is shared between the Nordic TSOs through agreements on the volumes of the different ancillary services each country is responsible for.
- In Sweden, no single actor is responsible for ensuring security of supply, and no security of supply objectives have been set. The responsibility for security of supply is split between different actors including Svenska kraftnät, other grid owners and power producers. This creates uncertainty and, in the absence of concrete objectives, increases the risk that important aspects are neglected. Svenska kraftnät is therefore of the opinion that the Swedish government should adopt a standard for security of supply.
- Sweden places no formal requirements or obligations on power producers to produce electricity, whether to produce or not is a commercial decision made within the regulatory frameworks that apply to the electricity market. Furthermore, no one bears responsibility for ensuring that an adequate level of generation capacity is available in the longer term.
- The role of regional grid owners is being reviewed; it is being developed to include subsystem responsibility.

For the power system to be operated and developed efficiently, it is important that the roles and duties of the various actors in the electricity market are clearly defined and generally accepted. If this is not the case, important areas may be neglected, increasing security of electricity supply risks in the longer term. In addition to requiring a functioning electricity grid, good security of supply also requires access to generating capacity and a clear regulatory framework that sets out the conditions for engaging in the electricity market.

Svenska kraftnät is of the opinion that the roles and duties of the various actors in the electricity market are currently not well defined and that, as a result, security of supply could be compromised in the longer term. Svenska kraftnät would therefore like to see a clarification of these roles and duties.

2.1 Security of supply and related responsibility

Security of electricity supply refers to the ability of the power system to maintain a normal, good quality supply of electricity to consumers. The model illustrated in Figure 1 describes Svenska kraftnät's understanding of security of supply in more detail, and serves to identify the roles and actors involved in providing security of supply.

The model divides security of supply into two component parts, adequacy and reliability. Adequacy refers to the ability of the electricity system to maintain sufficient generation and transfer capacity to meet consumers' demand for power and energy. Adequacy is therefore associated with static conditions

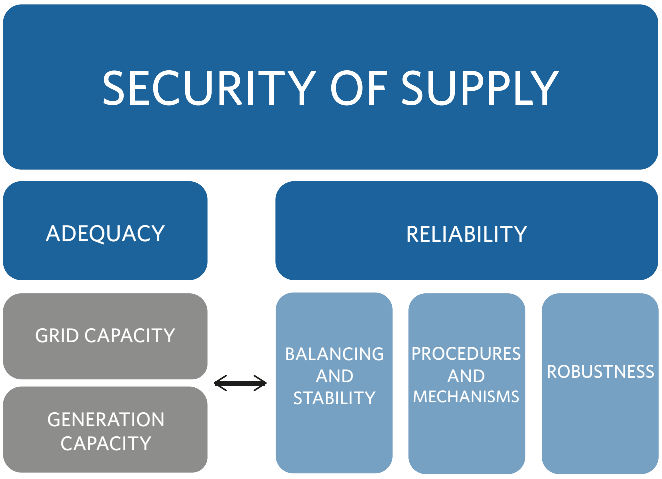

Figure 1. Svenska kraftnät's view of security of supply and its components.

and reflects the "static ability" of the system to deliver power and energy. How much is sufficient generation and transfer capacity is determined by given dimensioning criteria.

Reliability reflects the ability of the power system to respond to changes and disturbances within the system.

Sweden has not set a standard for security of supply. In the absence of a concrete definition of what constitutes sufficient security of supply, it is difficult for Svenska kraftnät to assess measures to improve security of supply. Svenska kraftnät is therefore of the opinion that the Swedish government should adopt a standard for security of supply.

2.1.1 Adequacy

Transfer capacity adequacy

Security of supply relies on there being enough transfer capacity in the power system to meet demand. The responsibility for the availability of transfer capacity rests with each grid owner; no one bears the overall responsibility for the Swedish system. As owner of the national transmission grid, Svenska kraftnät is responsible for its planning and expansion.

The electricity grid, especially at higher voltage levels, is not dimensioned to transfer all requested power in every situation; this would lead to significant over-investments in capacity with low utilisation. Improving grid capability beyond a certain point costs more – in the form of higher transmission tariffs and land use – than what it yields in socio-economic benefits, and cannot be justified. Therefore, the amount of power that can be transferred in some areas on the grid will be limited. These limits are handled differently by the different grid owners. Constraints in the transmission grid are reflected in the pricing of electricity in the wholesale market; Sweden is divided into bidding zones that reflect transmission constraints. This lies within the concept of adequate transfer capacity. Grid owners, however, have an obligation under the Electricity Act to connect generation and demand unless there are special reasons to not do it. Meeting these requirements while ensuring adequate transfer capacity is difficult because while transmission projects have very long lead times, changes in generation and demand are usually fast. This means that the development of the transmission grid cannot go hand in hand with the large and rapid structural changes currently taking place, for instance in metropolitan areas. In these areas, generation facilities are rapidly being closed, while demand is growing as a result of additional housing and new, large users like data centres. This puts increased pressure on transmission grids, and grid capacity is increasingly becoming a limiting factor. What constitutes adequate grid capacity can thus change rapidly, and the sluggishness that characterises transmission expansion together with optimisation requirements leads to limited possibilities for rapid increases in electricity demand if the level of security of supply level is to be maintained.

It is therefore important that the opportunities to develop the electricity grid are also included in society's development plans to avoid a negative impact on security of supply.

Generation adequacy

Generation adequacy refers to the ability of the power system to maintain a secure supply of electricity to meet demand, considering demand response. Generation capacity adequacy refers to both energy and power. Energy adequacy refers to the ability of available generation to meet demand over an extended period of time while power adequacy refers to the ability to instantaneously provide the desired power at all times in every withdrawal point.

In the interconnected European electricity system, generation resources used to meet a country's demand are not necessarily within the country's borders, and imports and exports affect both energy and power adequacy. This is particularly significant for countries like Sweden where most generation is weather-dependent, and will become even more so in the future. The energy capacity of hydro generation can vary substantially depending on rainfall: imports are needed during prolonged periods of low rainfall to assure security of supply, while prolonged periods of high rainfall result in an energy surplus that can be exported.

Historically, the level of power adequacy has been reduced in various areas by transfer capacity constraints, driving grid expansion. This will continue as the energy system changes, especially if nuclear generation resources being phased out in southern Sweden are replaced by weather-dependent resources further north.

Sweden puts no formal requirements or obligations on power producers to produce electricity, whether to produce or not is a commercial decision made within the regulatory frameworks that apply to the electricity market. Furthermore, no one bears responsibility for ensuring that an adequate level of generation capacity is available in the longer term. The state promotes investment in new electricity generation through subsidies including the electricity certificates system for renewable electricity generation. Svenska kraftnät is responsible for building cross-border interconnections and for assessing the need for further import or export capacity on socio-economic grounds. This means that Svenska kraftnät does not develop interconnections to improve security of supply. The main purpose is to fulfil a general responsibility to facilitate a well-functioning European electricity market. In general, however, increased trade capacity also makes a positive contribution to security of supply.

2.1.2 Reliability

Reliability relates to the power system's ability to withstand and respond to sudden disturbances including the loss of generation or demand, or loss of grid components. The level of reliability is reflected on the impact of a disturbance. A disturbance will more frequently lead to a larger loss of load (demand) in a system with a lower level of reliability. A lower level of reliability may also mean that it will take longer to restore disconnected demand or that it will be more difficult to return to a stable operating state that can withstand further disturbances following a fault. For this reason, reliability has been further divided into the areas of: balance/stability, procedures and mechanisms, and robustness.

Stability

A power system is dynamic: demand, generation and the grid are constantly changing. Many of the processes are slow in this context; demand changes during the year according to the season, but also during the day, between day and night and hour by hour. The power system also constantly experiences faster changes in connection with disturbances independent of the slower changes.

Disturbances affect a power system's fundamental parameters: current (power), voltage and frequency. How a system reacts to disturbances depends on the behaviour of generation and demand, as well as on the structure and components of the transmission and distribution grids. If a system's collective resources cannot handle the disturbance, the system risks collapsing, resulting in an extensive outage.

As system responsible authority, Svenska kraftnät ensures the stable operation of the power system. Since a system's ability to handle disturbances is highly associated with the behaviour of generators, generators must adhere to various requirements to connect to the electricity grid. Requirements relate to their ability to withstand changes in voltage and in frequency without their generation being affected. There may also be requirements that generators have a control system that actively controls its output to help dampen the oscillations that can arise in the power system following a disturbance.

To maintain a high level of reliability, a power system must be able to be quickly restored to a stable state where it can handle further disturbances after the initial disturbance has been addressed. Svenska kraftnät therefore needs access to various ancillary services to balance demand and supply and to ensure the security and quality of electricity supply.

Balancing

In a stable power system, demand including system losses must be matched by generation (including import/export) in every instance, regardless of what events occur, such as a line, generator or major electricity user being disconnected.

Market actors play an important role in system balancing. Balance responsible parties (BRPs) are responsible for balancing in the initial planning stage; the demand they are responsible for must be matched by generation for every hour of the day. This means that generation and demand in Sweden will, according to plan, be in balance during the upcoming day.

Deviations from BRPs' planned balance always arise. As system responsible authority, Svenska kraftnät is responsible for system balancing during the operating stage. Balancing is mainly done automatically using available balancing services. In case of major deviations, Svenska kraftnät contracts up and down regulation of generation or demand to restore the automatic regulation that has been activated due to imbalances.

Svenska kraftnät has no balancing resources of its own but arranges markets for balancing services to contract sufficient balancing capacity to balance the system. In addition, Svenska kraftnät has access to disturbance reserves that can be activated in exceptional situations following large disturbances that make it difficult to balance the system during short periods of time. In these situations, which are on the borderline between stability and balancing, both special generation resources and control systems on the HVDC links to other countries can be used to prevent system collapse. Svenska kraftnät also procures a national strategic reserve to ensure security of supply in the face of high demand during the winter months. The strategic reserve makes it financially possible for a number of generators that under normal conditions would not be able to compete with other generators to remain online.

Svenska kraftnät continuously assesses the effectiveness of existing arrangements to maintain system frequency by measuring frequency quality, among other things. These analyses clearly show that frequency quality in the Nordic power system has deteriorated in recent years. The deterioration of frequency quality indicates two sub-problems. One relates to the amount of inertia in the system. When the amount of inertia is reduced, the rate of frequency decline following the sudden loss of a large generating unit will increase. This leads to higher costs as a higher volume of frequency response is needed to manage the system within limits. The other sub-problem is an increase in how often and for how long system frequency is outside its normal interval without major disturbances having occurred. The latter is a measure of how well electricity market participants adhere to existing rules and ultimately of Svenska kraftnät's and the other Nordic TSOs' balancing strategy. If frequency is outside its normal interval when a major disturbance occurs, the risk of a major consequence increases as parts of the automatic response will be fully used and unavailable to manage the disturbance.

The responsibility for balancing the interconnected Nordic power system is shared between the Nordic TSOs through agreements on the volumes of the different ancillary services each country is responsible for. Svenska kraftnät and Statnett have started a review of current balancing arrangements in part to meet the challenges associated with controlling the Nordic frequency.

Procedures and mechanisms

The procedures and criteria applied to grid, operational and outage planning, capacity allocation and reserve management are paramount to security of supply. It is also important that market arrangements support the stable operation of the power system. Deficiencies in these areas generally mean that the operation of the power system is made more difficult. Security of supply is ultimately entirely dependent on market arrangements to deliver sufficient resources. Svenska kraftnät also believes that it is important to review the functional requirements that are placed on the resources that, for instance, power producers bid to the different balancing markets. It is also becoming increasingly important to follow up that these requirements are met so that the activation of resources results in the expected outcome. As new technical solutions for renewable electricity generation, storage and demand response emerge and start participating in balancing markets, the importance of clarifying these functional requirements increases.

Robustness

Security of supply also relates to how robust a power system is, i.e. how it responds to different types of disturbances. A power system with more redundancy will not necessarily manage the first fault better than one with less redundancy, but the second fault will be better managed. For instance, the possibility to quickly restore operations depends on whether there is access to reserve feed routes and spare parts to quickly repair faulty components.

As responsible for the transmission grid, Svenska kraftnät plans the transmission system on the basis of the well-established N-1 criterion. This means that the system is planned to withstand a single contingency such as the loss of a transmission system component without it leading to a loss of load. As system responsible, Svenska kraftnät plans the transmission system to withstand the loss of one large generating unit without risking the stability of the system.

FOTO: TOMAS ÅRLEMO

Power systems are increasingly dependent on very complex IT systems for control and monitoring. These systems provide many benefits in terms of efficiency, but also introduce new risks and vulnerabilities. Svenska kraftnät therefore has a major focus on IT security issues, both from an IT security perspective, and from a purely functional perspective since the consequences of failures in the IT systems can be very large.

For a power system to be robust in the long term, its components must withstand ageing. Ageing infrastructure should neither result in an increase in the number of failures nor lengthen the time it takes to address a fault. If, for example, a line is not renovated in time, the risk of poles collapsing in situations where they would not normally do so increases. Svenska kraftnät therefore devotes extensive resources to replacing ageing equipment on time. As a result of the transmission grid's age, this is increasingly important work to be able to continue to have high security of supply in the power system.

2.2 System responsibility

Svenska kraftnät is a state authority, tasked by the Swedish government to manage, develop and operate Sweden's transmission grid and interconnections in an economically efficient and environmentally responsible way.

There is reason to look further into Svenska kraftnät's roles and duties as system responsible authority. The current situation dates to 1992 when the Swedish Parliament established the guidelines for restructuring Sweden's electricity market. A key objective was the separation of the natural monopolies - the transmission and distribution grids - from the potentially competitive activities of electricity generation and electricity trade. This meant that security of supply responsibilities became more complex as responsibility for security of supply was split into a generation component and a transmission component. Generation and transmission, both fundamental to security of supply, have different areas of responsibility and entirely different conditions. Core system operation activities like maintaining system stability and overall system operation, while the responsibility of Svenska kraftnät as system responsible authority, require contributions from natural monopolies (the grids) and generators acting in competitive markets.

System responsibility is a public responsibility and means that Svenska kraftnät, through its own efforts and coordination of others' efforts, must ensure that system reliability is maintained in a cost-effective manner.

System responsibility is a key role, but it is a general responsibility and does not mean that Svenska kraftnät is responsible for operational reliability in every part of the power system. Each grid owner, regardless of voltage level, has a distinct responsibility under the Electricity Act to properly dimension its grid and to operate it within its technical and legal limits. Although maintaining operational reliability in the transmission grid relies on the operational reliability of the underlying grids being maintained and vice versa, Svenska kraftnät neither can nor should determine the operational reliability criteria that other grid owners apply. Instead, Svenska kraftnät is responsible for and has a mandate for operational coordination across the power system, i.e. to support optimal use of the grids by all connected resources.

Thus, the role of system responsible authority includes establishing the prerequi-sites for a stable operation of the power system. An important prerequisite is establishing the split of responsibilities and costs for selected solution strategies.

The challenges associated with the increased complexity of security of supply responsibilities were foreseen and discussed at the time the electricity market was restructured. The preferred solution was for Svenska kraftnät to address security of supply responsibilities through agreements. Actors must therefore follow terms and conditions set out in agreements. Svenska kraftnät was, however, given the right to issue regulations within the scope of its system responsibility. The rationale behind this decision was the risk of conflicts of interests between actors' commercial interests and their expected contribution to security of supply. Another reason why Svenska kraftnät was given the right to issue regulations is that it does not own and manage the 130 kV grids, as is customary in many other countries. Requirements set through regulations make it easier for Svenska kraftnät to agree on critical connection requirements for generators when there is another grid owner between the transmission grid and the generator. Svenska kraftnät is of the opinion that its right to issue regulations should be prolonged.

The role as system responsible authority is complex and involves many tasks. To facilitate the integration of European electricity markets, many aspects of the various countries' approach to system responsibility are being harmonised as European network codes and guidelines are implemented. Several changes will take place in the coming years in Sweden as the implementation of the European rules progresses.

2.2.1 Scope of system responsibility

In practice, system responsibility includes controlling and monitoring different factors that affect the stability and balancing of the power system. Svenska kraft-nät's Grid Supervisor bears the utmost responsibility for this in the daily operation of the power system.

System responsibility also includes many tasks outside the scope of power system operation. In the interest of acceptable operational reliability and to minimise market impact, Svenska kraftnät coordinates transmission outage plans with the maintenance plans of generators. Svenska kraftnät also proposes, with due motivation, requirements for generators that consider their impact on the entire power system.

Furthermore, Svenska kraftnät determines the need for automatic balancing ser-vices to quickly restore the power system to a new stable situation after a disturb-ance has occurred.

Svenska kraftnät also manages systems that protect the power system from collapse following extreme disturbances. An example is the automatic demand disconnection scheme that protects the system from complete collapse if, for example, two nuclear power plants are disconnected simultaneously.

2.2.2 Challenges with the current split of responsibilities in the electricity market

Power systems are constantly changing, but since the separation of ownership and operation of transmission systems from generation and other activities, electricity markets have not seen any fundamental structural changes. The purpose of more recent changes has been to facilitate a more efficient use of available generation and transfer capacity. In this context, the system operator role and other roles in the market have been well established.

It is expected that power systems will change more drastically in the future as new ways to produce, store and use electricity are introduced on a larger scale. This will bring about new direct technical challenges, challenging also how to ensure that the power system is managed in a safe and cost-effective way. Technical development means that it is no longer as clear if the ancillary services needed will come from generators or from grid components with corresponding characteristics. As a result, finding the most effective suite of products to manage the system and its corresponding division of responsibilities and costs between power producers and grid owners will become more challenging. In the future, ancillary services could also be provided through requirements, compensation mechanisms or pure market solutions.

Before the restructuring reform, investments in generation and transfer capacity were centrally coordinated as it was common for a single company to own both grid and generation capacity. The functioning and expansion of generation and transmission were connected and aimed to cost-effectively meet security of supply requirements in the power system. This holistic approach to security of supply is now lost.

A further challenge to security of supply is the split of responsibilities between Svenska kraftnät and the owners of regional and local grids. Svenska kraftnät sees a growing need to redefine the roles and duties of regional and local grid owners in the shift to a more flexible and decentralised power system. The introduction of Distribution System Operators (DSO) with subsystem responsibility should be considered. The reason is that in light of more distributed generation, local and regional grid owners are increasingly facing operational challenges similar to those Svenska kraftnät faces, but on a regional level. Svenska kraftnät is of the opinion that in the future, the need for cooperation, coordination and new governance structures will increase. Roles and duties must therefore be adapted to ensure continued good operational supervision and control to maintain high security of supply.

At present, Svenska kraftnät has no finished solution to these challenges, but will continue to work together with electricity market stakeholders on approaches to addressing these challenges.


PHOTO: TOMAS ÅRLEMO

3. FRAMEWORK AND PREREQUISITES

SUMMARY

International climate policy and European energy policy are having a growing impact on Svenska kraftnät's operations.

> Svenska kraftnät needs to comply with the requirements of European Commission regulations containing legally binding rules – known as network codes and guidelines – which take precedence over domestic laws.

> Eight Commission regulations have entered into force and are being implemented throughout the EU. The scope of the requirements set out under EU legislation is therefore already established.

An important prerequisite for the assessment of major new investment projects is that the assessment is based on socio-economic welfare. As far as possible, benefits will be quantified, but non-quantifiable benefits are also considered.

3.1 Climate, environment and energy policy

Energy and environmental policy are key driving forces behind the development of power systems. Political decisions taken at both national and European level will often have a direct impact on electricity markets. As the integration of national electricity markets in Europe progresses, the impact of European energy policy in Sweden will increase.

3.1.1 International climate policy

In December 2015, many of the world's countries reached a global, legally binding climate agreement, known as the Paris Agreement. Among other things, the Paris Agreement sets out a long-term goal to limit the increase in average global temperature to well below 2 degrees Celsius above pre-industrial levels, and to aim to limit the temperature increase to 1.5 degrees Celsius. The Agreement requires countries to prepare climate action plans and to revise them every five years with more ambitious targets. The energy sector and not least electricity generation are central to achieving climate targets. In the longer term, the Paris Agreement will therefore have a significant impact on the Swedish power system. The expected effects of the Paris Agreement included in the section "The Power System in 2040".

3.1.2 European energy policy

In February 2015, the European Commission presented a strategy for a European Energy Union designed to make energy more secure, affordable and sustainable. The Energy Union can be described as a working plan for developing the electricity and gas markets in Europe in the coming years. It aims to achieve progress in five key aras: energy security, energy market integration, energy efficiency, decarbonisation, and research and development.

Since the Energy Union strategy was presented, the Commission has published several packages of measures to ensure that the Energy Union is realised. The 2016 package "Clean Energy for All Europeans" contains a number of legislative proposals covering energy efficiency, electricity market design, renewable energy, and Energy Union governance. These proposals will have a major impact on Swedish energy policy as well as Svenska kraftnät's operations.

Proposals concerning electricity market design and integration will have the largest impact on Svenska kraftnät's core tasks of market development and operation, but other proposals may affect Svenska kraftnät indirectly. Worth noticing is that these proposals sometimes address the same issues being addressed by the European network codes and guidelines.

Through ENTSO-E, Svenska kraftnät has analysed and provided its opinion on a number of European initiatives and proposals. In addition, Svenska kraftnät has supported the Ministry of the Environment and Energy in its work with the Energy Union. During 2017, there are negotiations between member states and the EU Commission before the package is decided.

3.1.3 Swedish energy and environmental policy

In April 2015, the Swedish Government appointed a multi-party Energy Commission tasked with negotiating an agreement on long-term energy policy. In June 2016, an Energy Agreement was reached between five political parties. The Energy Agreement set out a Swedish target of 100 percent renewable electricity[1] by 2040. The proposals in the agreement will have a significant impact on electricity markets, including electricity generation, consumption, transmission and market design. Some concrete decisions that have been made to-date include the phase-out of the capacity tax levied on nuclear power, a reduction of the capacity tax levied on hydropower and an extension of the electricity certificate system to 2030. The Energy Commission submitted its final report[2] to the Government in January 2017.

Developments in environmental policy also affect energy markets. More stringent environmental standards can limit hydropower's ability to provide balancing capacity. The EU Water Framework Directive requires that water bodies including reservoirs are protected and enhanced to achieve good ecological potential; this can lead to a reduction in hydropower capacity if plants are forced to shut down[3].

3.2 More international cooperation

Svenska kraftnät has a mandate to promote an open Swedish, Nordic and European market for electricity. Consequently, Svenska kraftnät works in close collaboration with fellow TSOs in the Nordic and Baltic regions. Work focuses on developing a common Nordic strategy to meet the challenges associated with increased electricity market integrations and with an increasingly decentralised and weather-dependent electricity generation. Given the levels of interconnection of the Nordic power system, it is important that major challenges and solutions are discussed jointly.

Within Europe, extensive work is under way to achieve the single European market for electricity. The European Union's Third Energy Package of legislation (EC Directive 2009/72 on the internal energy market for electricity and Regulation (EC) No 714/2009 on conditions for access to the grid for cross-border exchanges in electricity) has been key in this work. Other important initiatives include the Energy Union, requirements for increased interconnection and the "Clean Energy for All Europeans" package. As a member of ENTSO-E, Svenska kraftnät cooperates with 42 TSOs from 35 countries.

PHOTO: TOMAS ÄRLEMO

3.3 European legislation

Svenska kraftnät and other TSOs play a central role in realising European climate and energy policies. Given electricity market integration, it is increasingly difficult for individual TSOs to act in an uncoordinated manner with the rest of Europe. Svenska kraftnät is essentially positive to the further integration of energy markets and the harmonisation of rules for the operation of transmission and distribution grids, and is actively engaged in European issues via ENTSO-E.

The Third Energy Package sets out two key tasks for ENTSO-E:

> provide input for European network codes and guidelines

> develop, every two years, a non-binding and EU-wide Ten-Year Network Development Plan (TYNDP).

3.3.1 European network codes and guidelines

The Third Energy Package provides the legal basis and procedures for ENTSO-E and ACER to develop EU-wide rules to effectively manage cross-border electricity flows. To date, a number of grid codes and guidelines governing the design, operation and planning of the European energy sector have been developed. Once they enter into force, these network codes and guidelines become directly applicable Regulations, and will therefore have a significant impact on the Swedish power system.

As a member of ENTSO-E, Svenska kraftnät has participated in the preparation of proposals for network codes and guidelines based on the "framework guidelines" developed by the Agency for the Cooperation of Energy Regulators (ACER). Once ENTSO-E has submitted these proposals to ACER for its opinion, ENTSO-E's influence is relatively limited, although ENTSO-E maintains a dialogue with ACER and the European Commission until the European Commission presents the final legislative proposal. Svenska Kraftnät supports the Swedish government during negotiations, as national energy ministries will be involved in discussions of legislative proposals.

Once a network code or guideline enters into force as a Commission regulation, ENTSO-E's and Svenska kraftnät's work continues with its implementation. EN-TSO-E's work is especially noticeable in the guidelines as the guidelines require that many methods are prepared jointly by European TSOs.

The European network codes and guidelines and the process to develop them affect Svenska kraftnät's ability to meet future challenges. Because European network codes and guidelines take precedence over national legislation, Svenska kraftnät's actions must comply with European network codes and guidelines. At the same time, European rules provide a regulatory framework that enables and drives the development of solutions

1. According to the Renewable Energy Directive (2009/28/EC), the share of renewable electricity is calculated as the ratio between electricity produced with renewable sources of electricity and electricity consumption, but an equivalent definition is lacking in the scope of the Energy Agreement.
2. Energy Commission report 2017: Kraftsamling för framtidens energi
3. Hydro power's regulation contribution and value for the electricity system - report from the Swedish Energy Agency, Svenska kraftnät and the Swedish Agency for Marine and Water Management

CONNECTION CODES			
NC RfG	Network Code on Requirements for Generators	Technical requirements that generators must respect to connect to the grid.	Entered into force on 17 May 2016
NC DCC	Network Code on Demand Connection	Specifies requirements for connecting large renewable energy generation plants as well as demand response facilities.	Entered into force on 7 September 2016
NC HVDC	Network Code on High Voltage Direct Current Connections (HVDC)	Specifies requirements for long distance direct current (HVDC) connections.	Entered into force on 28 September 2016

MARKET CODES			
GL CACM	Guideline on Capacity Allocation and Congestion Management	Sets out methods for calculating and allocating capacity for the day-ahead trade and intraday trade	Entered into force on 14 August 2015.
GL FCA	Guideline on Forward Capacity Allocation	Sets out methods for calculating and allocating capacity for the markets with longer time horizons than the day ahead.	Entered into force on 17 October 2016
GL EB	Guideline on Electricity Balancing	Regulations for a well-functioning market for balancing power	Entered into force on 18 December 2017

OPERATING CODES			
GL SO	Guideline on System Operation	Contains what in the process was previously divided into the three following components: > OS – Operational Security > OPS – Operational Planning and Scheduling > LFCR – Load Frequency Control and Reserves	Entered into force on 14 September 2017
NC ER	Network Code on Emergency and Restoration	Procedures and measures for operating situations with serious disturbances or collapses	Entered into force on 18 December 2017

Table 1: European network codes and guidelines under implementation

to meet the challenges that European power systems are facing.

As Table 1 shows, eight network codes and guidelines have been adopted and have entered into force. This means that the work towards an integrated European electricity market has entered the implementation phase.

3.3.2 Ten-Year Network Development Plan

The biennial TYNDP for electricity presents ENTSO-E vision for how to develop the grid in the coming years so that it can effectively contribute to achieve European climate and energy targets.

The TYNDP provides a comprehensive and transparent overview of projects that are considered of common European interest; it therefore provides key decision support for grid investment at both regional and European level, but is not formally binding. Draft TYNDPs are published for public consultation, allowing stakeholders to get involved in the development of the European electricity grid.

A number of scenarios ten to fifteen years into the future provide the baseline on which TYNDP projects are assessed. The 2014 and 2016 TYNDPs use four scenarios, reflecting possible futures for electricity markets.

TYNDP projects are assessed against different indicators, including electricity market benefit, the integration of renewable electricity generation, losses and permit issues. Not all indicators are quantified in financial terms; this means that project assessments do not rely on simple cost-benefit analyses. Projects may also be grouped to show that, in many cases, several reinforcements together provide the desired outcome.

Analyses and identification of potential grid reinforcements, called Project Candidates, are made within ENTSO-E's grid planning regions. Sweden is part of the Regional Group Baltic Sea.

Regional groups publish regional investment plans containing potential grid reinforcements. Regional investment plans provide the basis for a joint assessment of a project's electricity market benefit and profitability. This evaluation is done centrally within ENTSO-E. Regions may also analyse their own scenarios in addition to those presented in the TYNDP. These may therefore differ depending on how different regions have performed their analyses.

3.4 Assessing the socio-economic welfare of investments

Svenska kraftnät's mission includes ensuring the development of an economic and efficient power system from a socio-economic perspective. As the system responsible authority, Svenska kraftnät strives to balance generation and demand cost-effectively and to manage the grid effectively and securely. As transmission grid owner, Svenska kraftnät develops the transmission grid after assessing the socio-economic welfare of the different investment options.

Socio-economic welfare assessments provide important input when deciding whether to proceed with the different investment options. These assessments are updated as necessary prior to every decision in the investment process as conditions often change in the course of the work. For instance, the estimate of the total investment cost gradually becomes more precise as the planning for an investment progresses, as developments unfold which can affect the benefit of an investment.

Transmission investment is generally driven by one or more of the following: to meet new capacity requirements, to replace ageing assets, to accommodate new electricity generation connections or electricity demand patterns, or to support operational reliability. As an initial step, Svenska kraftnät investigates a range of solutions that address the above deficits. Some deficits must be addressed, for instance to comply with connection obligations and operating reliability criteria. The solutions identified are considered according to the increase in socio-economic welfare that they deliver. Alternatives to investment in transfer capacity are also considered but Swedish legislation sets limits for which solutions Svenska kraftnät may adopt; investment in generation capacity or energy storage is not allowed.

The Energy Markets Inspectorate has been tasked with establishing the guidelines for assessing the socio-economic welfare of transmission investments. This assignment will be presented in April 2018. Svenska kraftnät welcomes greater clarity in this area.

3.4.1 Swedish or Nordic benefit?

Svenska kraftnät has a mandate to promote integrated Nordic and European electricity markets. The Nordic Council of Ministers has directed the Nordic TSOs to pursue investments in transmission that increase socio-economic welfare across the Nordic region.

Increased interconnection between the Nordic countries is financed by each country in proportion to the benefit it receives. Svenska kraftnät's investment decisions are therefore based a comparison of Svenska kraftnät's share of the cost of the investment and the investment's increase of socio-economic welfare in Sweden.

3.4.2 Methodology

To assess the socio-economic welfare of future transmission grid investments, Svenska kraftnät looks at how a number of parameters change as a result of grid reinforcements. Various types of model simulations are carried out to determine how different reinforcement options affect different aspects of the power system, including markets for electricity, security of supply, and transmission losses. When relevant, the impact of grid reinforcements on the cost of countertrade and various forms of reserves is also analysed. Energy scenarios representing multiple views of the future form the basis of the analysis. In addition to the main scenarios, sensitivities are used to increase the robustness of the results in relation to the greatest uncertainty factors in the main scenarios.

When possible, benefits are calculated in economic terms and expressed as annual averages. Annual averages are added and expressed as an economic present value using the calculation time and interest rate that is appropriate for each investment.

As part of the socio-economic welfare assessment, benefits are compared to the cost of each investment. Benefits that, by their nature, cannot be quantified or are difficult to quantify are also included in the assessment. Therefore, an investment can show positive socio-economic welfare effects despite negative profitability. Similarly, an investment with a positive estimated profitability may not show positive socio-economic welfare if non-quantifiable benefits/effects are deemed to have a significant negative impact. Non-quantifiable socio-economic benefits include a more resilient power system less vulnerable to failures and local environmental effects. Svenska kraftnät develops its methodology continuously and will attempt to quantify as many benefits as possible in the future.

4. THE POWER SYSTEM IN 2040

SUMMARY

As a starting point for the analysis in the System Development Plan, Svenska kraftnät has developed a reference scenario for 2040. The objective is to illustrate and indicate system challenges that can be expected up to 2040 considering a number of identified driving forces. The scenario is based on currently known decisions and political directions at an international, European and Swedish level. There are several measures that might or will be implemented by various actors, including Svenska kraftnät, which can affect what the system will look like in 2040. The reference scenario represents a changed power system in several aspects, of which the most central are summarised below:

> The decommissioning of nuclear power and some other thermal power will mean that available system inertia will decrease, which degrades the frequency stability of the Nordic system. A growing proportion of intermittent electricity generation increases the need for flexibility in the power system while the supply of system inertia is limited.

> Greater consumption and lower generation capacity leads to a degradation of the generation adequacy in southern Sweden. In the reference scenario for 2040, power shortages may occur in southern Sweden for around 400 hours per year unless sufficient flexible generation or demand response is available. Some of this flexibility is already available, mainly in the form of power-intensive industries.

> In the reference scenario, large price differences between SE2 and SE3 arise after year 2030. The results from the analysis indicate a need for increased transfer capacity in Cut 2, even beyond already planned reinforcements.

> Both the reduced generation adequacy in southern Sweden and the price differences between SE2 and SE3 imply that it is important to investigate the extent to which greater demand response, energy storage or new flexible generation can contribute to improve the generation adequacy and reduce the price differences.

It is difficult to make a statement about the long-term development of the power system and electricity market and, in a time perspective up to 2040, it is not meaningful to speak about forecasts. There are a number of different driving forces – for example, political, legal, technical and economic – that will affect how the electricity market and power system will develop. The outcomes of some of these driving forces are rather certain and can therefore be seen as long-term trends which can form the basis for many different scenarios. Other driving forces are instead characterised by a significant uncertainty, which can lead to a large number of possible outcomes in a long-term perspective.

The scenario presented here is thereby not a forecast for what 2040 will look like. It should instead be regarded as a reference scenario based on a number of identified driving forces, which are developed with the aim of illustrating and pointing out system challenges that can be expected up to 2040. What the system will actually look like in 2040 will of course be affected by a number of different measures that can be implemented by various actors, including Svenska kraftnät.

4.1 Assumptions on development towards 2040

Even though it is difficult to forecast what the power system and electricity market will look like in a long-term perspective, it is necessary for Svenska kraftnät to make assumptions regarding future development in order to plan and proactively implement required measures. Svenska kraftnät therefore uses scenario analysis to investigate various possible development paths and evaluate possible measures for the future. The planning horizon has previously reached to 2030, even if, in recent years, some more long-range explorative analyses have been carried out in collaboration with other actors. Now, there is a need to expand the time horizon and the Energy Agreement provides some fundamental frameworks that can be used to build a scenario

PHOTO: ANNIKA ÖRNBORG/VATTENFALL

for the power system up to 2040.

The assumptions that form the basis of Svenska kraftnät's reference scenario for the period 2020-2040 are described below. The scenario is conservative in the sense that neither revolutionary technical breakthroughs nor radical changes in market conditions are assumed. It is also assumed that, apart from the already planned development, no expansion of the transmission grid will occur. In other words, the results from the analysis can in some sense be interpreted as the consequences of "business as usual". The reference scenario is the starting point for further analysis of the future power system and various parameters in the scenario can be varied to investigate the impact on, for example, pricing, transmission needs and balancing conditions.

4.1.1 Fuel prices and European development

This scenario is based on fuel prices and prices of CO2-emission rights according to IEA's scenario "Low Oil" (2015), which is a version of "New Policies Scenario" (NPS). NPS is IEA's base scenario that builds on the assumption that planned national climate measures will be implemented, even if the concrete measures are not yet identified. "Low Oil" means a slower increase in the oil price resulting from the extraction of shale oil. The extraction of shale oil can increase quickly when the market price of oil increases, which, in turn, can slow down the rising market price.

The development of the European electricity market is based on a scenario that has been developed in the ENTSO-E group, Regional Group Baltic Sea. The assumptions for electricity consumption and expansion of renewable generation have thereafter been adjusted for the larger countries according to updated national plans.

4.1.2 Changed electricity consumption

Electricity consumption is a central parameter for the development of both the electricity market and for the power system. The electricity consumption in 2040 will be affected by factors such as population growth, economic growth, new technology and policies. In this chapter, some of the driving forces that Svenska kraftnät have identified are presented. This list is not complete and in the next 20 years, there will probably be new technologies and developments that nobody has yet considered. Despite this, it is of interest to follow up on the identified changes.

In the scenario up to 2040, a slight increase of the annual electricity consumption is assumed, from roughly 140 TWh today to around 150 TWh in 2040. This volume is in line with what the Swedish Energy Agency[4] (143 TWh) and IVA[5] (160 TWh) have in their scenarios. However, it should be emphasised that the uncertainty around the future electricity consumption is considerable. The scenarios for electricity consumption developed within IVA indicate an outcome range from the lowest outcome of around 100 TWh to the highest outcome of around 260 TWh. In the scenarios that indicate the highest growth in electricity consumption, all the different driving forces interact for increased electricity consumption. The largest contributions come from the electrification of the transport sector, steel manufacturing and cement manufacturing. Despite the marginal change of electricity consumption in the reference scenario, the differences are larger in the individual sectors. Rising electricity consumption in some sectors is balanced by a decrease in others, mainly through energy efficiency improvements.

Increased energy efficiency is driven by three factors: technology, economics and policies. Modern technology leads to more efficient products, at least if this is in demand by the

4. Swedish Energy Agency report: Scenarier över Sveriges energisystem 2016
5. IVA final report: Vägval el: Elanvändningen i Sverige 2030 och 2050

electricity users. A new refrigerator is, for example, more energy efficient than an older one. The price of electricity is another strong driving force for lower electricity consumption. In addition to the electricity-intensive industries, which have electricity as a raw material, money can for example be saved in the operation of large properties. In addition, homes with direct electric heating can reduce their costs through better insulation or by switching to a heat pump. Large parts of this energy efficiency improvement take place through a combination of technology and economics, as well as legislative requirements. The political dimension is governed by the EU Energy Efficiency Directive[6]. The objective of the directive is to achieve the target of a primary energy savings of 20 percent by 2020. Concrete measures are, for example, energy surveys in large companies and energy measurement in buildings, including residential properties.

Reduced consumption of electricity also contributes to increased energy efficiency which is a result of an increase of GDP requiring less and less energy. Apart from technical energy efficiency enhancement, this also includes the energy savings that arise from new or changed activities contributing to GDP, for example through a shift from manufacturing industries to the service sector. The future efficiency improvement of electricity consumption is deemed to be within the range of 3-4 percent per year.[7] In November 2016, the five parties behind the Energy Agreement agreed on targets for energy efficiency improvements for Sweden by 2030. According to the agreement, Sweden shall have 50 percent more efficient total energy use by 2030 compared with 2005 (measured in terms of energy input in relation to GDP).

In terms of driving forces for increasing electricity consumption, the population growth is the largest. Statistics Sweden's (SCB) forecast indicates a population growth of around 18 percent by 2040.

The transport sector is also expected to contribute to increased electricity con-sumption in this scenario. When transitioning from fossil fuels to electricity, electricity consumption will increase. If Sweden's nearly 5 million cars are converted to electricity, electricity consumption will increase by around 12 TWh per year. An increase in the number of electric vehicles appears very likely, but it is uncertain how quickly this increase will be and when it will gain speed. In addition to the conversion of cars, greater investments in electric-powered buses in public transport are also expected. In addition to the road traffic, there is also the rail-bound traffic. Here, it is mainly the new Metro in Stockholm and the proposed high-speed railway that can increase electricity consumption.

Another area that might lead to greater electricity consumption is hydrogen gas production, Power-to-Gas (P2G). The first application is the production of gas for hydrogen gas-powered vehicles. Since the cycle of electricity-gas-electricity has a lower efficiency than pure electric power, this leads to higher electricity consumption than for pure electric cars. P2G is also considered as a way of taking care of surplus from renewable electricity generation, where the surplus energy is then stored in the existing gas grid. There are also plans to replace fossil fuels with gas in various industrial processes. One example is to remove coal and coke from steel production, which would reduce the emission of $CO2$.[8] This could increase electricity consumption by around 20 TWh per year.

IT is another sector where electricity consumption is expected to increase. The Nordic region is considered to have good conditions for the installation of data centres and several large IT companies are already established here. A reliable electricity supply, good infrastructure and a cold climate are factors that can continue to attract more investments. Proximity to customers (short response times) is, however, a factor where the Nordic region has greater difficulty to compete with places on the European continent. In addition to this, competition is extensive both between municipalities and countries, so all planned data centres will probably not become reality. Electricity consumption may also increase among private users with growing numbers of electronic products both at home and work.

In summary, Svenska kraftnät assumes that the various driving forces for greater electricity consumption are largely balanced by energy-efficiency improvements. A small net increase by around 10 TWh/year by 2040 is attributed to electrification of road transports and new types of industrial establishments, such as data centres. However, there is a considerable uncertainty and if the efficiency improvement effects decrease and/or if further consumption increases occur, the annual consumption might be as large as 260 TWh. This is a fundamentally more challenging scenario for the Swedish power system than the opposite with an overall decrease in consumption.

Besides changes in electricity consumption, an urbanisation where the population is moving to the larger cities is taking place. Together with a greater demand from data centres, this creates a challenge for the electricity grids in the metropolitan regions.

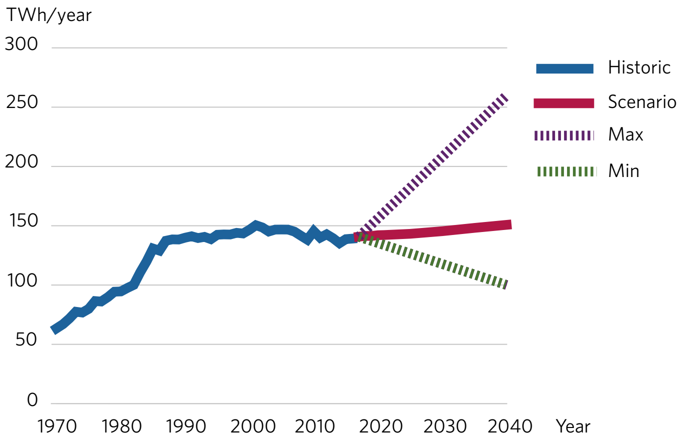

Figure 2. Sweden's electricity consumption. Maximum and minimum scenarios are taken from IVA .[9]

6. DIRECTIVE 2012/27/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC

7. IVA Final report: Vägval el: Elanvändningen i Sverige 2030 och 2050.
8. http://news.vattenfall.com/sv/article/f-rnybar-el-och-v-tgas-l-sningen-f-r-co2-fritt-st-l
9. IVA Final report: Vägval el: Elanvändningen i Sverige 2030 och 2050.

4.1.3 Changed electricity generation

In the reference scenario up to 2040, electricity generation changes with the assumption that all nuclear power is decommissioned, and that wind power and to some extent solar power is expanded while other generation is largely presumed to be unchanged.

The assumption of the nuclear power decommissioning is based on political decisions already made and on the Energy Commission's report. The base of the scenario is that the four oldest reactors are closed no later than 2020 since the owners will not invest in improved emergency core cooling. The Energy Agreement sets a target for 2040 of 100 percent renewable electricity generation, but also states that this is not an end date for nuclear power. In the reference scenario, it has been assumed that all remaining reactors will be closed by 2040. In addition, it is assumed in the scenario that the reactors will be closed gradually in the period up to 2040. This can, for example, be due to a somewhat larger need for measures or a serious fault arising, which is too costly to resolve to justify continued operation. In this scenario, it is therefore assumed that one reactor is closed before 2030, two before 2035 and the last three before 2040.

As previously stated, this is not a forecast for the decommissioning of nuclear power. In order to illustrate the system challenges, however, it is of particular interest to analyse a situation with less nuclear power and in particular the situation when all nuclear power is closed. If an assumption of a technical life expectancy of 60 years for the reactors is used instead, all reactors would be removed from operation by 2045. A longer lifespan for nuclear power would thereby mean that some of the effects illustrated here could be postponed by a few years.

In the Energy Commission's report, it is also suggested

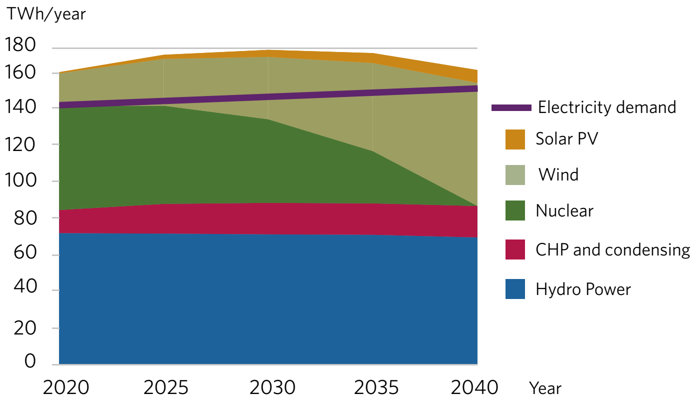

Figure 3. Swedish energy balance in the scenario during 2020-2040. The net balance increases until 2030 to then decrease until 2040. Wind power is built throughout the analysis period, and the nuclear power closure gains speed in 2030. The curves in the figure are based on values for every five years. The closure of nuclear power reactors will therefore mean greater step-wise changes than is apparent in the figure.

that the electricity certificate system is expanded by another 18 TWh and extended until 2030. In this scenario, it is assumed that 12 TWh of this goes to new Swedish wind power, 3 TWh to renewal of existing Swedish wind power, and that 3 TWh goes to new Norwegian wind power before the common Swedish-Norwegian electricity certificate system closes for new farms in 2022.

In addition, in the reference scenario, it is also assumed that around 7 TWh will be invested in solar power. The increase in solar power is assumed to come mainly from investments in properties that can benefit from the various support systems. In the reference scenario, however, the expansion of commercial solar farms is assumed to be held back by lacking profitability.[10 11]

Hydro power is considered to be fully developed at present. The four protected rivers will not be further developed and the local environmental permits make it very difficult to expand capacity in existing facilities. The total annual generation is deemed to increase as a result of climate change with rising inflow, but installed capacity is unchanged. In this scenario, no increase in the regulating ability of the existing hydro power has been assumed. If the EU Water Directive is implemented in an unfortunate manner, there may be a risk that the capacity to regulate hydro power generation is limited due to the requirements expected to be placed on environmental measures in power plants or due to changes of permits.

The expansion of CHP (combined heat and power) is limited by the need for heating and is therefore deemed to be largely unchanged. Even if more properties are connected to district heating grids, a warmer climate and more energy-efficient properties will balance the increase in the demand for heating.

As shown in Figure 3, Sweden is expected to maintain a positive energy balance, even if it decreases up to 2040. Generation adequacy will, however, be significantly worse, something that is clearly apparent in the results from the analyses of the reference scenario.

PHOTO: TOMAS ÄRLEMO

10. Swedish Energy Agency: Scenarier över Sveriges energisystem 2016,ER 2017:6; 4,5 TWh 2040
11. Swedish Energy Agency: Förslag till strategiför ökad användning av solel, ET 2016:16; Vision 2040:7 – 14 Twh/år

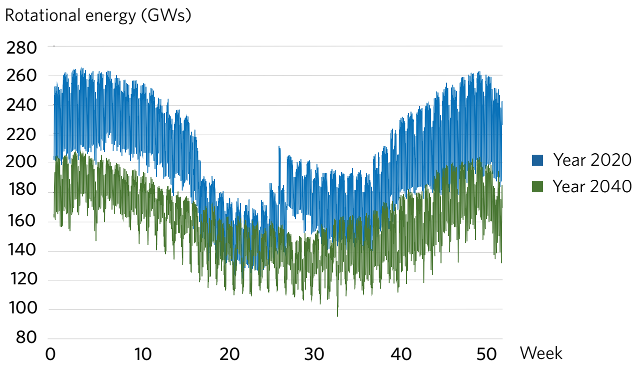

Figure 4. Simulated inertia in the Nordic synchronous area for 2020 and 2040. The curves represent the mean of 33 weather years.

4.2 Reference scenario for the power system in 2040

According to the assumptions made, a scenario has been developed until 2040. The results should be consistent with the detailed assumptions; generation is closed if it is unprofitable and new investments only take place if they are profitable. According to the assumptions, it is mainly wind power that is profitable to build, first with the support of the electricity certificate system and, later, on a fully commercial basis.[12] The majority of the wind power that is built is onshore, but up to 7 TWh is expected to be offshore. Some of the important implications of the reference scenario are summarised below.

4.2.1 Reduced inertia

Already in the assumption of a gradual decommissioning of nuclear power, it is clear that several heavy synchronous generators will disappear from the power system. This leads to a decrease in the annual mean inertia from 202 GWs to 159 GWs between 2020 and 2040.[13] The lowest value changes from 121 GWs to 95 GWs for the same period. The new generation that is added consists of wind power and solar power that do not contribute with any further mechanical system inertia.

Since wind and solar power have a marginal generation cost equal to zero, or below zero if subsidies are included, it will also primarily be hydro power that regulates down in the event of a surplus in the system.

4.2.2 Higher share of intermittent generation

With a growing share of intermittent generation in the power system, the need for balancing increases, which must be handled by the dispatchable generation. As long as the wind varies in line with electricity consumption, everything is fine, but at times when the wind decreases at the same time that electricity consumption increases, the balancing need becomes significantly more extensive.

Even if hydro power is a major asset in terms of balancing both electricity consumption and renewable generation, there are limits set by the permits. Many power plants are designed to manage the daily variations of the electricity consumption. Wind power and solar power generally did not exist in the system when today's hydroelectric power plants were built.

4.2.3 Increase in power shortage

According to the underlying assumptions, the analysis shows that it is mainly wind power that is expanded as nuclear power decreases; at first with the financial support of electricity certificates up to 2030 and then on commercial grounds. Solar power is also expanded with the help of various support systems. According to this scenario, by 2040, Sweden has around 67 TWh wind power and 7 TWh solar power. With such an amount of renewable generation, nuclear power is replaced in terms of energy, but the weather-dependent generation means that there will be many hours with low prices and many hours with high prices as a result of power shortages.

Despite many hours with a high electricity price, the assessment is that the average annual price is not high enough for investors to be willing to make investment decisions in new

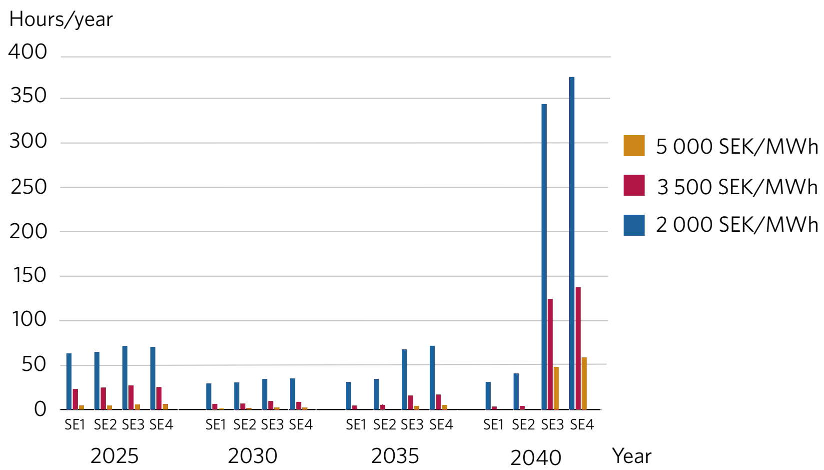

Figure 5. Average number of hours when some form of flexibility will be needed in the market according to the scenario.

12. Hydro power and waste-fired co-generation is also profitable, but the potential for expansion is deemed to be small.
13. Current scenario combined with data from ENTSO-E's project Inertia2 that is studying the system inertia in the Nordic synchronous system.

generation. In addition, future investments may be negatively impacted by a general uncertainty about future developments.

When nuclear power according to this scenario is decommissioned by 2040, there is a risk that southern Sweden (SE3 and SE4) will experience an average of nearly 400 hours per year with power shortages when some form of flexibility will be needed in the market. Part of this flexibility already exists, mainly in the form of power-intensive industries. For extreme weather years, however, the scenario indicates a significantly higher number of hours with power shortages.

In order to study the market effect of the high number of shortage hours, it has been assumed that some resource will be added to the market even if it at present is unclear what resource this will be. In this scenario, a supplement of around 2,600 MW of some form of flexibility will be required to avoid the power shortage, which amounts to more than today's strategic reserve. Even if there is extensive uncertainty in this figure, the need for a greater amount of flexibility is clear.

Today's flexibility mainly comes from electricity-intensive industries, which means that the price is somewhat high. Today, it is difficult to predict the price level at which flexibility will be added to the power system in 2040, but Svenska kraftnät has chosen to price this resource in line with the flexibility that exists in the market today, i.e. in the interval SEK 2,000-5,000/MWh (EUR 200-500/MWh). Altogether, it is important to investigate the extent to which greater demand response, energy storage or new flexible generation can contribute to improving generation adequacy.

4.2.4 Price differences and bottlenecks

Compared with today, two things are changed in the scenario. The bottleneck moves from Cut 4 to Cut 2 and the price difference increases between northern and southern Sweden.[14] The price difference over Cut 2 (SE2-SE3) is expected to be around SEK 160/MWh (EUR 16/MWh) with the above assumptions. For extreme weather years, the difference is considerably larger.

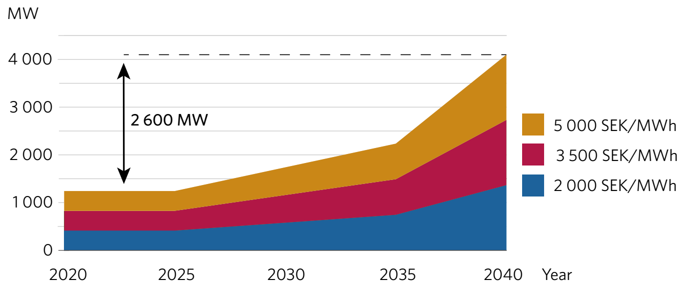

Figure 6. Assumed increase of flexibility needed to avoid power shortage. Just over 2.6 GW of planned resources must be added compared with today's situation. The power reserve, which for the upcoming season is 750 MW, is not included in the diagram since the Act on Power Reserves only applies until 2025.

A 50 percent decrease of the prices for the flexible resource is deemed to result in nearly a 50 percent decrease of the price difference over Cut 2 to around SEK 90/MWh (EUR 9/MWh), calculated as an annual average.

It is important to note that the price differences are a result of the assumed prices for the flexible resource that needs to be added. Today, it is not possible to tell the price levels at which the future flexibility will be activated. The objective of this analysis is not to forecast the electricity price in 2040, but to indicate that large amounts of flexibility may be needed to replace electricity generation that is not profitable to invest in.

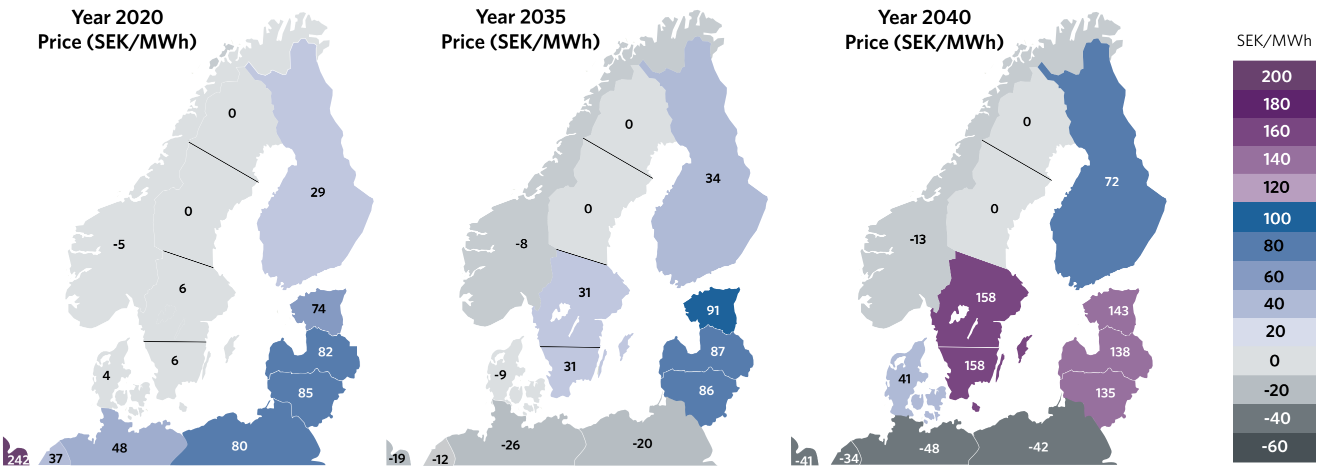

Figure 7. Price difference relative to bidding zone SE2 per other bidding zone for 2020, 2035 and 2040. For 2040, the price difference over Cut 2 (SE2-SE3) amounts to around SEK 160/MWh (EUR 16/MWh). In the simulation, Norway and Denmark have been divided up into different price areas, which is not shown by the figure.

14. Constraint refers to the bottlenecks in a north-south direction in the Swedish power system. Cut 1, 2 and 4 coincide from north to south with the boundaries between the Swedish bidding zones.

PHOTO: TOMAS ÄRLEMO

SYSTEM DEVELOPMENT

The introductory section of the System Development Plan generally describes how various driving forces provide an illustration of the direction in which the power system will develop up until 2040. With this as a basis, and based on the results from various analyses, clear challenges to the long-term security of supply were described.

The on-going development in the electricity market will lead to major changes in the generation units that lead to large challenges for the power system. The sub-stantial changes that primarily affect the power system are that the number of generation sources with synchronous generators (such as nuclear power) decreases in favour of other types of sources and more intermittent electricity generation. This shift results in several different consequences and creates challenges for the power system.

Fewer synchronous generators lead to less inertia in the power system. This affects several parts of the system, but mainly the possibility of keeping the frequency within set limits. The new type of electricity generation, of a more volatile nature like wind and sun, is increasing and will place higher demands on the possibility of keeping the power system in balance.

Another consequence is difficulties in being able to guarantee adequate power in every part of the country, especially during the times when consumption is high and the wind is not strong enough for wind power to cover the need for electricity consumption. In those cases, other generation, import or reduced consumption, must cover the deficit. The opposite problem will also be the case, i.e. that a high wind power generation coincides with low electricity consumption which results in a surplus of electricity.

Further, new electricity generation is not located at the same places as the generation being closed, which means that the grid capacity in the system is another challenge. This is reinforced by the need of a higher installed capacity in order to produce the same amount of energy that is produced with today's electricity generation. Insufficient grid capacity between bidding zones or towards other countries will therefore lead to both longer periods of different electricity prices and larger price differences within the country and to the surrounding areas.

In the following parts of the System Development Plan, the various challenges in the power system and the measures and changes that Svenska kraftnät will work on in the upcoming ten-year period is further discussed in more detail. An important part of the solution is that the entire system is being developed as a whole. The System Development Plan therefore focuses on both operational and market-related changes, as well as measures to develop and expand the grid.

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5. POWER SYSTEM STABILITY

SUMMARY

The future challenge lies in establishing the power system's stability margins and adapting the control of all components so that they support the stability in the system in line with the available capacity. In concrete terms, this aims to ensure the system's frequency, voltage and rotor angle stability. In this perspective, more general measures are also needed to improve the stability in the future system. Svenska kraftnät is working, among other things, to develop the capability for real-time monitoring as well as counter-measures and automatic regulation of the stability phenomena.

Frequency stability

The recently finalised joint Nordic projects that were aimed at analysing the present situation and required measures indicate that a new strategy needs to be developed for future frequency control. Svenska kraftnät is now working together with the other Nordic TSOs to develop such a strategy. Some parts of the strategy will be comprised of the following:

> Development of tools to estimate how much inertia is available in the system.

> Development of a solution to be able to reduce the dimensioning incident when necessary.

> New requirements for ancillary services for primary control and their performance for ensuring system stability. This solution manages frequency stability down to a certain level of inertia given the currently largest dimensioning incident.

> Further development of requirements with regards to the current levels of inertia. This may also include new faster ancillary services and adaptation of the market to meet the system's needs.

Voltage stability

The strategy for voltage control that Svenska kraftnät is now developing will, among other things, contain the following:

> Development of new requirements for dynamic voltage regulation for various kinds of connections and generation.

> Svenska kraftnät will, to a greater extent than before, make investments in facilities that can supply dynamic voltage regulation.

Rotor angle stability

Less inertia in the system also means that the risk for rotor angle instability increases. Svenska kraftnät is therefore working on the following:

> Improving the possibilities for monitoring the phenomena through new technology and better tools in the operational centre.

> Developing new measures to be able to dampen power oscillations.

The stability concept was mentioned previously in relation to the system's reliability. In this chapter, the meaning of the stability concept is developed, as well as in which way the stability is challenged by the changes in the power system. In addition, an overview is provided of the investigations that are under way and a description of the direction for the work of Svenska kraftnät in the future.

5.1 The complex power system

As previously mentioned, many parallel processes are under way in a power system that must be monitored and controlled in a coordinated manner in order for the system to be stable and operationally reliable. Consumption and generation vary continuously and with them, parameters critical to the system, such as current, voltage and frequency. The variations concern not only the amplitude of the oscillations or how much current, voltage and frequency change in different events; the speed with which the variations take place are also of significance and vary from minutes to milliseconds. These phenomena are based on physical laws, which are the basis for how the power system is operated. In other words, the power system is a dynamic and complex system that, from a technical regulation perspective, is usually described as "a huge multi-variable process that works in an environment of constant change".

Designing a large power system with the goal of cost-effectively ensuring stable operation is a complex and continuous process that is never completely finished. History has shown that new phenomena can arise in power systems during shorter or longer development phases. These phenomena are of different natures, but have in common that they can lead to instability if they are not countered through monitoring and control. In many cases, these "new" instability phenomena have arisen without being noticed until after they have caused major disturbances. Large power outages entail large costs and the ability to continuously develop methods and tools to monitor and guide the power system towards its steady state is central to the system's continued security of supply and cost efficiency.

A stable system means that equilibrium is created between the often-counteracting forces that a power system encompasses. Since both small and large disturbances upset this balance (stability), the power system's ability to quickly achieve a new state of equilibrium after a disturbance must also be taken into account when the system's stability is assessed.

The dynamics mentioned above mean that every power system is in constant "motion" around its state of equilibrium. Disturbances in the form of short circuits, earth faults, disconnection of generation and other power system components mean that quantities, such as current, voltage and frequency can very quickly vary and begin to oscillate towards critical levels for the system stability. This can create several simultaneous reactions in the power system's many parallel processes.

A critical power system component being disconnected by a protection system can affect the power system in different ways. For example, it can entail changed transfer patterns, changed voltage levels, synchronous machines changing rotation speed (frequency), regulators for frequency and voltage in both generation and grid components being activated, changes in consumption, and further protection systems being activated that exist to protect individual components. Such a chain reaction weakens the system and leads to unsafe operation of the power system, a state when the power system becomes very vulnerable to the consequence of a further, normally "trivial" disturbance suddenly being able to lead to a collapse of the entire system.

PHOTO: TOMAS ÅRLEMO

A stable system requires that the variations that arise during normal operation can be managed and that there are functions in place that ensure this. It is also necessary that there are functions in place to quickly return the system to a new steady state following a disturbance. These critical functions go under the collective name of Ancillary services and differ depending on the stability problem to be resolved.

5.2 Grid strength and inertia – critical factors

Grid strength and inertia are two very critical power system factors that, until recently, have not received much attention. The reason that they are now receiving attention is the fact that the level of grid strength and inertia determine boundary conditions for the design and function of ancillary services and system protections. These factors, among others, now moving towards new levels highly affect the power system's function. It is therefore likely that comprehensive changes need to be made and a new route for system stability as a whole needs to be set out (an overall strategy), but also for the separate parts of the system, which are brought up later in the chapter.

Current stability strategies have worked well, but are mainly adapted to the power system built up before the electricity market reform. The protection systems and critical regulation functions (ancillary services) included in the strategies have not been designed for the more economically optimised and volatile power system that is now emerging. The development that is under way will lead to a new direction where the system over time will be stressed harder and where the stability margins will decrease. The power system will then be significantly less robust than it has been and the requirements on observability and controllability will increase markedly.

PHOTO: TOMAS ÄRLEMO

Greater observability and controllability therefore becomes an important part of the new strategies that must be implemented to be able to drive the power system stably with this new situation. It is such a fundamental change that the new strategies also need to build partly on new ways of thinking, a new stability philosophy for the power system needs to be developed.

There is no off-the shelf solution available today, but extensive development work is under way in several areas. However, it is important to emphasise that the changes that are mentioned here in one way or another will affect all participants in the electricity market.

What at present can be said of the direction for upcoming strategies is the following:

- The requirements on ancillary services will generally increase and will much more clearly reflect and be adapted to the system's needs. In some cases, significant changes in the requirements can also be expected.
- New and developed ancillary services will be needed.
- The requirements on data and tools for monitoring and controlling system stability in the operating phase will need to increase; follow-up will also become central.
- The requirements to test the ancillary services' actual performance will need to increase compared with before, both in terms of meeting requirements for delivering existing ancillary services, but also for new technology with potential to provide new ancillary services.
- More proactive and long-term work is needed that not only focuses on current problem areas, but also continuously develops expertise and approaches in the stability area as a whole. The efforts implemented within R&D will have a strong connection to the new strategies.

Below is a more indepth review of challenges, solutions and on-going work in the three areas that power system stability can be divided into: frequency stability, voltage stability and rotor angle stability.

5.3 Frequency stability

Frequency stability as a concept is about the power system's ability to maintain a steady frequency after being subjected to a major disturbance in the balance between generation and consumption. If the disturbance's scope is within the N-1 criterion, the ancillary services for frequency control (primary control) shall automatically handle the situation and balance the system within five to ten seconds. The frequency can then be restored manually (tertiary control) to the same level as before the disturbance.

In disturbances beyond the N-1 criterion, the primary control is not dimensioned to restore the frequency to a new stable situation on its own. In such a situation, a number of protective functions should instead be activated to stabilise the frequency. The objective of these functions is to stabilise the system with a minimal amount of involuntary disconnection of electricity consumers. In extremely strong frequency drops, this can however not be avoided without the disconnection of consumption becoming necessary to save the system. Traditionally, frequency stability has been related to the reserves and generally, it can be said that frequency instability depends on incorrect function in the primary control or an incorrect set of requirements for primary control, inadequate reserves or an inadequate power of the protective system for extreme disturbances. A boundary condition for the requirements set on both the primary control and the protection systems is the system's total level of inertia. This means, upon declining levels of inertia, that the primary control and the protective functions at a certain lower level will no longer be able to stabilise the frequency if they are not successively adapted to the new conditions in the power system that decreasing inertia, among other things, will lead to.

The inertia, reserves and protective systems are, however, not the only factors that affect frequency stability. The maximum instantaneous imbalance (dimensioning incident) that can arise is another factor and the power system's self-regulation upon a frequency drop is another. The latter is a phenomenon that means that the consumption to some degree decreases in a frequency drop – a phenomenon that partly helps to stabilise the frequency. How large the contribution varies and is affected by a number of different factors.

Temporarily and marginally reducing the dimensioning incident, i.e. the maximal instantaneous imbalance that the system can be subjected to, is also something that reduces the risk of instability. This should only take place if it is necessary and if it can be justified socio-economically. In this context, it is important to emphasise that the largest generation facilities drive up the costs for primary control during the whole year, in that the larger the generation loss that can take place in a power system, the more reserves must be available to the TSOs.

Since there is a dynamic between inertia, the largest instantaneous imbalance and reserves, it is not obvious that the challenge with lower inertia shall only be handled by upgrading primary control or by increasing inertia. There are technical limitations for the existing machines' ability to deliver exactly what the power system needs in the form of rapid and stable primary control. It is possible, during brief periods, to regulate the largest permitted incident (instantaneous imbalance) to a level that the power system at that particular moment can handle without greater risk of consumption being disconnected.

In addition, it is not a given that more of today's reserves can ensure the frequency stability as the level of the inertia is decreasing. Only increasing the amount of reserves is not necessarily the solution to the problem of a reduced level of inertia. This can be explained with the following example: The primary control works so that it measures the frequency and tries to counteract the frequency deviations by adjusting the generation. However, it takes some time for the automatic system and the power plants to adjust generation. With a large amount of reserves, there is a risk that the primary control overcompensates. This results in the primary control again trying to compensate, but in an opposite direction. The risk is then that the system will start to oscillate with the control system.

There are various solutions for handling a power system with less inertia, but regardless of which option(s) are chosen, this will definitely entail greater requirements on the primary control delivering ancillary services with the right quality.

Besides the three main components that form the basis of frequency stability, inertia, reserves and the dimensioning incident (instantaneous imbalance), it is also the behaviour of facilities (technical characteristics) upon disturbances that is of major importance to the power system's ability to return to a new stable state. These technical characteristics are regulated through connection codes or agreements and specify for example what conditions facilities must withstand without being disconnected and in which conditions they may be disconnected. These requirements will make it possible to avoid several facilities being disconnected at the same time in connection with normal disturbances.

There is no doubt that it is becoming more challenging than before to stabilise the power system in the future. It will become more important than ever to have a detailed overview of all parts of the power system to ensure the security of supply in real time and that everything works as intended.

Since there are several factors that affect the frequency stability, various solution strategies must be investigated. At present, an extensive investigation effort is under way with regard to future frequency stability. As frequency stability concerns the entire synchronous system, this work is taking place at the Nordic level. Insights and conclusions in this work indicate that a new more developed frequency stability strategy needs to be developed. Among other things, a well-developed approach is needed to find a dynamic optimum between size of the dimensioning incident, level of inertia and primary control at the same time that the requirement on frequency is always included.

In order to obtain documentation for an upgraded frequency stabilisation strategy in the Nordic region, four parallel investigation projects are under way that have strong dependencies among themselves. One project shall prepare and recommend a method for establishing and evaluating the frequency quality from a socio-economic perspective. Another project shall

PHOTO: TOMAS ÄRLEMO

PHOTO: HASSE ERIKSSON

prepare proposals on new requirements for the reserve ancillary services FCR-N and FCR-D. A third project is reviewing and suggesting a new structure of the system for disconnecting consumption relative to the new conditions that will prevail. The fourth project aims to investigate and answer high-priority questions that concern the challenges of less inertia and recommend solutions and continued investigation work. The prioritised tasks for this project are:

> Developing an improved method to be able to estimate the level of inertia in real time.
> Proposing measures for handling low levels of inertia.
> Developing a method to be able to estimate the margin for frequency stability.

In recent years, there have been many discussions about so-called synthetic inertia. This can be described as the extra contribution in the form of electrical torque that is obtained through controlling proportionally towards the frequency change per time unit. The synthetic inertia can, for example, come from wind power plants where the power withdrawal is briefly increased or decreased by using the wind power plant's stored rotational energy. Synthetic inertia means that the response from a unit emulates the response from the inertia of a synchronous generator.

A broader concept is Fast Frequency Reserve (FFR) which is an ancillary service with a rapid activation time, but that does not necessarily emulate the synchronous generator's inherent characteristics. Voluntary momentary reduction of electricity consumption, wind farms and batteries are some examples that can conceivably provide such a service. The objective of the service is to counteract the impact of a lower inertia by providing a rapid reserve that briefly delivers power. Technically, HVDC connections can also provide a very fast and sustainable service on condition that there is power available on the other side of the connection. This service is not currently available in the Nordic system, but is something that is being studied further in this fourth project. In the future, GL EB provides the TSOs possibilities to reserve capacity on interconnections for ancillary services, which create conditions for utilising HVDC interconnections for this purpose. Svenska kraftnät has confirmed that the frequency quality and frequency stability will be a major challenge in the future and measures need to be implemented. The projects that have been implemented and are still under way indicate that a new strategy needs to be developed that ensures the future frequency control.

5.4 Voltage stability

Voltage stability as a concept concerns a power system's ability to maintain stable voltage levels and return to a new steady state after having been subjected to a disturbance. For a system to maintain voltage stability, it must be possible to meet the system's need for reactive power in each individual part of the grid. If this condition is not met, the system is considered to have voltage instability, with smaller margins until voltage collapse can occur. A voltage collapse can entail an electricity outage for all or parts of the system. Voltage collapse was the reason for the latest major disturbance in southern Sweden (in 2003).

Slow voltage instability is mainly caused by the consumption's behaviour in disturbances as it tends to be restored to the level it was at before the disturbance, without adapting to the system's now reduced ability to transmit power. In the worst

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case, this process can lead to voltage collapse.

The reason that every part of the grid must have the right amount of reactive resources is because of the physical laws that say that reactive power cannot in principle be transmitted over large distances. As the flow of reactive power in the transmission grid is essentially driven by voltage differences between different areas, this means that transmission of reactive power can degrade the voltage instability in the event of disturbances. It is therefore important that the reactive power is produced or consumed in the right places in the grid to ensure voltage stability. This necessary geographic spread of the reactive resources is the explanation why it is not suitable to have a market place for reactive power.

Another critical factor is the type of power system component that contributes to the voltage control. There are two main groups of components, the dynamic step-less components (generators and power electronics) and the breaker-connected, stepwise components such as shunt capacitors and shunt reactors.

The dynamic components are in many respects superior to the breaker-connected components, but they are also much more expensive. At the same time, there is a technical limit to the share of breaker-connected components that can exist in the system without it becoming unstable. For the system to be able to effectively and safely return to a new steady state after a disturbance, it must contain a certain amount of rapid, dynamic, step-less components.

Decommissioning of nuclear power with synchronous generators that are directly connected to the transmission grid means that the number of dynamic components that are of significance to the transmission system's voltage stability decreases. This means that Svenska kraftnät needs to compensate for this deficiency with grid components. Which dynamic functionality is to be placed on the components needs to be investigated, but it is clear that more grid components will be needed with dynamic characteristics in the southern parts of the transmission grid. It is not a major technically complicated problem, but increases the costs for the operation of the transmission grid.

The new generation connected to grids at lower voltage levels in the system cannot replace the voltage control in the transmission grid. Voltage control must take place at the right point and reactive power cannot effectively be transported between voltage levels in the system. The efficiency then simply becomes too low.

The requirements on voltage control, both in terms of maintaining the voltage within the limits set by the grid codes and reactive reserves for voltage stability, are generic. This means that it is difficult to rely on voltage regulation from generation that cannot be planned since the ancillary services from this generation also cannot be planned. In addition, the previously mentioned problem with low efficiency from reactive resources on the transmission grid when they are connected to grids with lower voltage levels remains.

The expansion of intermittent power generation has also changed the active power flow pattern. New generation has been connected to regional and local grids in central and southern Sweden, which has resulted in the transmission grid occasionally being significantly unloaded, resulting in high voltages. Altogether, this means that the need for voltage control measures for the transmission grid is growing and will grow further. This accordingly applies to measures to be able to both up and down regulate the voltage.

PHOTO: HANS BLOMBERG/VATTENFALL

Voltage regulation with connected synchronous machines will also in the future play a major role in northern and central Sweden where the majority of the hydro power generators are located. However, this assumes that they are connected to the grid when they are needed and that the regulation is properly set.

With the current market model, operating situations will arise where variable, non-plannable generation facilities push out part of the hydro power generator's active generation from the market in terms of price. Since there are significant difficulties in formulating a well-functioning market that provides the generator owners' economic incentive to operate the generators in synchronous operation, i.e. produce or consume only reactive power to regulate the voltage, it is not possible to count on the generators always being available. It is therefore necessary for parts of the voltage regulation to take place through expansion of voltage regulating equipment in the transmission grid and Svenska kraftnät therefore needs to ensure that this is done. In most cases, this means that breaker-connected resources need to be installed. When the remaining nuclear power plants are decommissioned, the voltage regulation using synchronous machines will probably be replaced by voltage regulating grid components. The HVDC connections (NordBalt and SydVästlänken) that are now connected in southern Sweden will also contribute to an improved voltage regulation through their ability to supply reactive power to the transmission grid.

To ensure that the transmission grid has a stable voltage regulation that guarantees a continued stable power system, these challenges are currently being investigated. This investigation shall lead to a strategy that shall establish the direction for how the transmission grid's voltage regulation shall be designed.

5.5 Rotor angle stability

The concept of rotor angle stability comprises how the rotor angles for the various synchronous machines connected to the power system relate to each other. Hence, rotor angle stability primarily concerns dampening the relative movement that naturally arise between the generators' rotors. A measure of this movement is how much the rotors' relative angle difference varies. If the angle difference becomes too large between the system's generators, it can result in one or more generators losing synchronisation with the rest of the system which results in disconnection. In the event of disturbances in the system, the rotor angles will change and power oscillations can arise between the generators. The size of these power oscillations are determined by the size of the disturbance, its duration and how the system's dampening works. If these power oscillations become too large, it can lead to system collapse.

Rotor angle stability is divided into two sub-groups, small signal stability and transient stability. Small signal stability means how the system handles small disturbances, such as the mechanical power in a generator changing by ten percent. Transient stability instead means the system's ability to handle major disturbances, such as short circuits.

The grid that connects the generators serves as an elastic system and the angle difference between the generators' rotors depends on the power transfer in the grid. The stability can be preserved if the grid is "sluggish" and has enough grid strength to handle the disturbance and return the system to a new stable state by the oscillations that follow the disturbance being dampened out.

Natural measures for improving a power system's stability (grid strength) are grid reinforcements, increasing the short circuit power or voltage support.

The change that the system is now undergoing will mean that it is operated under new conditions and power flows, for which the current control system is not optimised. The changes in the power system contribute to reducing the margins for the rotor angle instability due to:

> Generation that is not synchronously connected to the system (solar and wind) having characteristics different to synchronously connected generation and does not contribute short circuit power to the system in the same way. The contribution to the short circuit power from non-synchronously connected generation depends largely on how it is controlled during the process. The grid strength will decrease with a changed generation mix and the margin to instability decreases.

> Synchronous generators in the Nordic power system are equipped with dampening add-ons (Power System Stabilisers, PSS) that automatically help to dampen oscillations in the system. Hence, the change means that even the dampening contribution from PSSs decreases, which can shrink the margins to rotor angle instability even more.

> A third factor that can decrease the margins to instability is the fact that the transmission in the system increases and that more cross-border interconnections will be built. This means that more power will be transferred over larger distances, which in itself will lead to a risk that rotor angle instability can arise. The same development occurred in the 1980s when transmission between the Nordic countries increased and oscillations arose. Then, rotor angle instability was what in several cases limited maximal transfer between the bidding zones.

It should be emphasised that different stability phenomena often form the basis of transfer limits and less often the power lines' ability to withstand load. Accordingly, the grid infrastructure cannot in these cases be utilised to its full capacity.

Observing the rotor angles and finding ways to dampen the oscillations without building new power lines is very cost effective. Historically, it has been possible to solve the problem by changing the parameters for the PSSs in the synchronous generators and thereby adapt their dampening contribution to the prevailing situations. But when the number of synchronous generators decreases, it is not possible to rely solely on adjusting the PSSs. Other measures will also be required.

Another problem regarding the rotor angle instability is that it has not been technically possible to monitor this phenomenon in real time. To-date, rotor angle instability has had to be studied through simulations using mathematical models of the power system. With the development that Svenska kraftnät now sees, the risk of oscillations will probably increase in the future. To continue to not have the possibility to observe this phenomenon in real time would mean that larger safety margins must be introduced, which ensure that rotor angle instability does not occur. New technology in measurement and monitoring systems (WAMS/PMU) is now enabling the establishment of tools to be able to observe the rotor oscillations in real time and also be able to develop new measures to dampen oscillations.

PHOTO: TOMAS ÄRLEMO

The new technology may also serve as an aid for analyses and for validating grid models and stabilisers (PSSs) so that they are correctly set. This also provides opportunities to better observe, understand and control the system regarding other phenomena, such as subsynchronous resonance. Observing stability margins in real time is therefore a development that is becoming very important for being able to handle the future system. Measures that will be developed aim to not allow rotor angle stability to limit transfer capacity. For this, automatic systems are needed combined with instructions for the operators. High standards must be set on developed measures, and the new automatic systems introduced must undergo rigorous safety tests that ensure that they work correctly and that they work when they are needed so that they do not worsen the situation in certain operating states.

Svenska kraftnät is working intensively to develop and establish such a system, both in Sweden and at the Nordic level, and today has a WAMS system in place. However, a large amount of continued development work is needed before there is a tool in the operational centre to be able both to observe and to control the power system in a desirable way. The goal is that all Nordic TSOs will have access to similar visualisation of the stability margins in real time. There shall also be support in the operative stage for the right measures to be able to be carried out at the right places so that necessary stability margins are preserved. The plan that Svenska kraftnät is working on together with the Nordic TSOs is intended to put a prototype system in place in a few years.

6. BALANCING

SUMMARY

A larger share of weather-dependent electricity generation and the new requirements resulting from European legislation mean that the Nordic balancing model needs to be developed at a faster pace than previously. These changes mean that the need for flexibility is increasing and market participants need clearer incentives to promote flexibility. The requirements for the resources used in balancing will also need to be developed.

Svenska kraftnät is continuously developing the Nordic balancing model to provide clearer responsibilities and incentives for maintaining the balance per bidding zone and a more efficient utilisation of balancing resources. Svenska kraftnät, Statnett and Energinet have agreed on an in-depth cooperation in the balancing process and plan to introduce a new Nordic balancing concept. The new concept improves the capability of dealing with the volatility created by an increasing share of intermittent generation and meets the requirements set in the network codes. The new balancing concept is planned to be implemented gradually during the next five years.

The balancing process can be divided into three main sub-processes: system design and development, planning and operation, and settlement. Within each part, there is a need for development.

System design and development

Within system design and development, a number of important development stages have been identified that Svenska kraftnät will work with in the next few years:

> A more dynamic handling of the ancillary services based on operating situation and the development of strategies and tools to streamline and ensure the right volume of ancillary services in the operating stage.

> The various balancing services will be given slightly changed roles. For example, mFRR is expected to mainly be used for proactive balancing and aFRR for corrective balancing upon a measured imbalance. It might also be necessary to introduce new, faster ancillary services, and to develop the requirements for the various services.

> To enable the exchange of balancing services across borders, the possibility of reserving transfer capacity for balancing purposes will be necessary. The benefit of doing this must be weighed, however, against the reduced benefit of trading electricity across the border.

> Demand response and energy storage will gain increased significance in balancing. For some purposes, demand response and energy storage may be technically more appropriate than production. At present, pilot projects are under way in aim of identifying existing barriers and challenges to be able to achieve commercial use of demand response and energy storage.

Planning and operation

The increased requirements also mean that the operational centre is facing new challenges. This means that several measures need to be implemented, including:

> A more extensive collecting of real-time measurements. This gathering of information does not only include measurements from Svenska kraftnät's facilities, but also measurements from generation facilities, regional grids and other European transmission operators.

> Svenska kraftnät's operational centre is in the middle of developments both towards a centralised European electricity market and with major local challenges due to an increased share of generation and demand response at lower voltage levels. An improved coordination with both subsystem operators for

SUMMARY (CONT.)

regional grids and transmission system operators is therefore necessary. For example, there is a greater need to exchange information when new types of operating situations are to be managed.

> Expanded IT support that is adapted to new needs to visualise events is a prerequisite for the operator to be able to quickly understand the operating situation and perform correct balancing measures.

Other development efforts include:

> Development of Nordic and European FRR platforms to enable market connection to the balancing market.

> Transition to MACE control.

> Information published to the market participants closer to real time: Svenska kraftnät is positive to this on the condition that the publication does not negatively affect operational reliability or distort competition.

> Coordination between the various balancing services so that the services' total contribution meets the system's need in the future as well.

Settlement
In addition to covering costs, settlement shall also create clear incentives and price signals for the market participants. The most central development stages are:

> The imbalance settlement period's length being shortened to 15 minutes. Clearer price signals are thereby created for the participants in the balancing market and the pricing more clearly reflects the real-time value of balancing energy. A 15-minute imbalance settlement period will be introduced in 2020 according to the current timetable.

> A single balancing position and one price settlement are expected to replace the current Nordic settlement model with two positions (for generation and consumption) and two prices for generation. The prerequisites for the changes are not established, but are subject to an on-going European harmonisation work based on the Commission guideline GL EB.

> Correct price signals based on results from the project Full Cost Balancing. Marginal pricing and a clear reflection of the imbalance price in the event of shortages are important principles.

This chapter describes challenges, as well as planned and possible changes of the balancing process that Svenska kraftnät deems necessary to ensure an effective balancing of the system in the future. Here, the balancing of the system is described based on a holistic perspective, which thereby includes the instantaneous frequency stability.

The balancing market shall be able to ensure adequate and long-term incentives for the market participants to create good conditions for flexibility in electricity generation and electricity consumption. It shall also promote the development of new flexibility. This flexibility means that the participant in question can increase or decrease its electricity generation or electricity consumption when required and is a necessity for the future operation of the power system. A lack of flexibility will in the long-term risk security of supply as well as hamper a safe expansion of intermittent electricity generation.

The balancing process needs to create sufficient incentives for market participants and be able to answer the following questions to support a market-oriented balancing model:

> What balancing services and volumes are needed?

> When are they needed?

> Where should the reserves be located?

They need to be included in the signals or incentives the market creates for market participants and communicated to the market participant through price signals in the balancing market, with regard to capacity, energy, settlement of imbalances or relevant processes for reporting and/or pre-qualification.

6.1 Drivers of change

The work of developing the balancing process so that it also continues to meet its requirements is primarily motivated by one or more of the following driving forces:

> Changed climate goals and the consequences of these in the form of changed generation and use of electrical energy.

> The objective of achieving a common European energy and balancing market.

> Technical development, which creates much better possibilities to automate, control and monitor the power system, as well as integrate demand response or distributed generation and new tools for effective balancing and market integration.

Figure 8 illustrates what needs and opportunities these driving forces create, and what consequences it leads to.

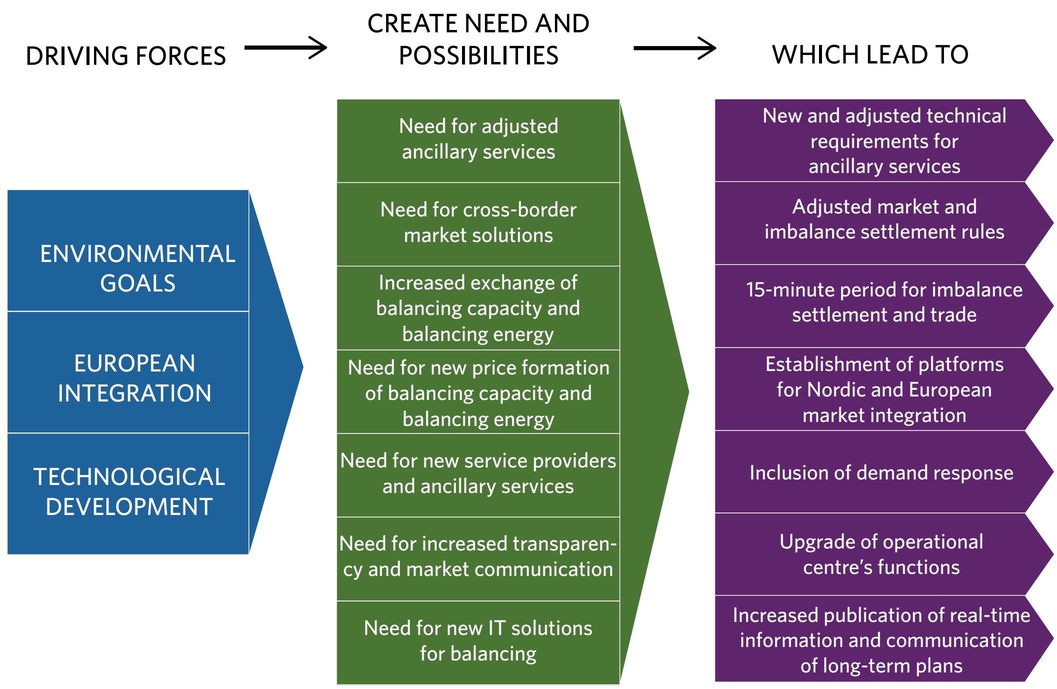


Figure 8: The driving forces for change of the balancing model create new needs and enable solutions.

Together, the driving forces create new needs and functional requirements for the balancing process, as well as new opportunities and alternative solutions. For example, programmes of measures where the power system expertise collaborates with new IT solutions and changes in the regulations and incentive models that control the balancing market today. Another example is the increasing market integration, both in the form of new cross-border interconnections and common European market rules, which create major challenges and needs for development. At the same time, this is an important part of the future comprehensive solution.

The new balancing model is therefore in the middle of the intersection point between several different driving forces. At the same time, the driving forces set different conditions and must therefore be weighed against one another, but they also enable new solutions.

6.1.1 Types of imbalances

Imbalances can be divided into different types based on their underlying cause. The TSOs can to a varying degree predict these different types of imbalances.

The market structural imbalances originate from the trade in the electricity market taking place on an hourly basis and the electricity consumption varying continuously. Structural imbalances are differences between the planned electricity trade per hour (MWh/h) and the forecast continuous outcome (MW).

During hours with rising electricity consumption, down regulation of generation is necessary at the beginning of the hour while up regulation is needed at the end of the hour. The opposite is true for hours with decreasing electricity consumption. If the trade instead takes place in 15-minute periods, the generation will be adapted in four steps during the hour, which reduces the structural imbalances. Structural imbalances can also arise for other reasons. Generation changes in generators do not take place instantaneously and there are system limitations for how quickly HVDC connections can increase or decrease the power flow. This means that large, rapid changes in consumption or supply do not always have time to be matched by corrective actions.

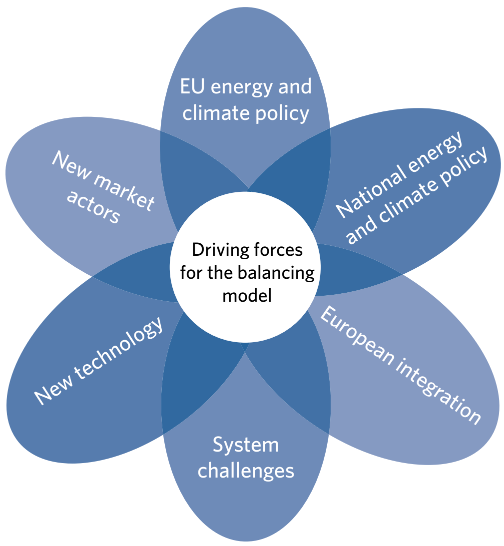


Figure 9. The balancing model is in the intersection between several driving forces that set the terms and must be weighed against one another.

TYPE OF IMBALANCE	UNDERLYING CAUSES	NATURE OF THE IMBALANCE	ANCILLARY SERVICES NEEDED FOR BALANCING	TREND	MOTIVATION OF TREND
STRUCTURAL - MARKET RELATED	Market structure	Moderate - slow	Generation shifts	Decreasing	Shorter electricity trade periods
STRUCTURAL - TECHNICAL LIMITATIONS	Limitations in power changes	Moderate - fast	FCR-N and aFRR	Increasing	More HVDC connections
FORECAST ERROR	Difference between forecast and outcome for supplied and consumed power	Slow	mFRR and aFRR	Increasing	Larger share of intermittent generation
DISTURBANCE	Unplanned major events	Fast	FCR-D	Increasing	More often due to more N-1, such as large wind farms and more HVDC links.
STOCHASTIC	Unplanned minor events	Fast	FCR-N	Increasing	Larger share of intermittent generation
SPECIAL REGULATION MADE BY TSO	Grid reasons	Slow	mFRR	Unchanged	
STRATEGIC	Imbalances due to plans not being followed	Slow	aFRR and mFRR	Decreasing	Incentives to follow plans

Table 2: overview of imbalances, the day's solution and future trend.

Forecast error is the difference between forecast and outcome for momentarily supplied and consumed power. This is expected to increase in pace with a larger share of intermittent generation. In the long term, the forecasts' uncertainty can decrease by developing improved forecast methods.

Disturbances mean that large generation facilities or larger individual electricity users suddenly change their input or output. Stochastic imbalances are smaller disturbances that continuously occur in the power system and are expected to increase with a growing share of intermittent generation.

Special regulations are used to manage limitations in the electricity grid and these activations can also create imbalances.

Strategic imbalances are caused by the market participants not following reported plans.

The aforementioned types of imbalances are summarised in Table 2.

6.2 Long-term strategy for balancing

Within the Nordic region, confidence in the Nordic balancing model has been extensive and the general perception has been that it in several ways is superior to equivalent models in Europe. The Nordic model has been lifted up as a role model in several crucial issues for how balancing should be done. This perception has in many cases been characterised by the network code work through the Nordic actors trying to guide the development in the direction of a balancing model of a Nordic type.

During the last few years it has become clearer, however, that there is reason to question this approach. The long-term strengths of the European target model and its contents that are proposed in the network codes have become increasingly clearer. At the same time, an insight has grown forth that the Nordic model cannot fully handle the future system challenges. The current model does not distribute responsibility and economic burden correctly, and it also lacks the conditions to benefit from the on-going European harmonisation in balancing. Svenska kraftnät has therefore together with Statnett decided to further deepen the cooperation on the Nordic balancing process and prepared a concept for the future balancing of the Nordic power system. The further design and implementation of the new balancing concept, including IT development, will entail extensive work in upcoming years. According to the current plan, a gradual implementation will take place in the next five years. At present, the TSOs in Sweden, Norway and Denmark agree on a deeper cooperation in the balancing process.

6.2.1 The new Nordic balancing concept

The developed model for balancing is based on proven technologies combined with powerful IT solutions. Based on this model, it is possible to trace a number of overall design aspects. In the report, "Nordic balancing concept" [15] there are 12 such design aspects. The main principles for these are:

> The power system is divided into so-called LFC areas corresponding to today's bidding zones. Together, the LFC areas comprise one or more LFC blocks. The aim is to describe the Nordic control structure, which is the area structure that the responsibility for balancing is based on. All sub-processes as well as dimensioning, activation and settlement are formulated based on the control structure.

> The balancing market applies 15-minute trading periods as well as 15-minute imbalance settlement periods. The main

15. Svenska kraftnät and Statnett report 2017: The Nordic Balancing Concept

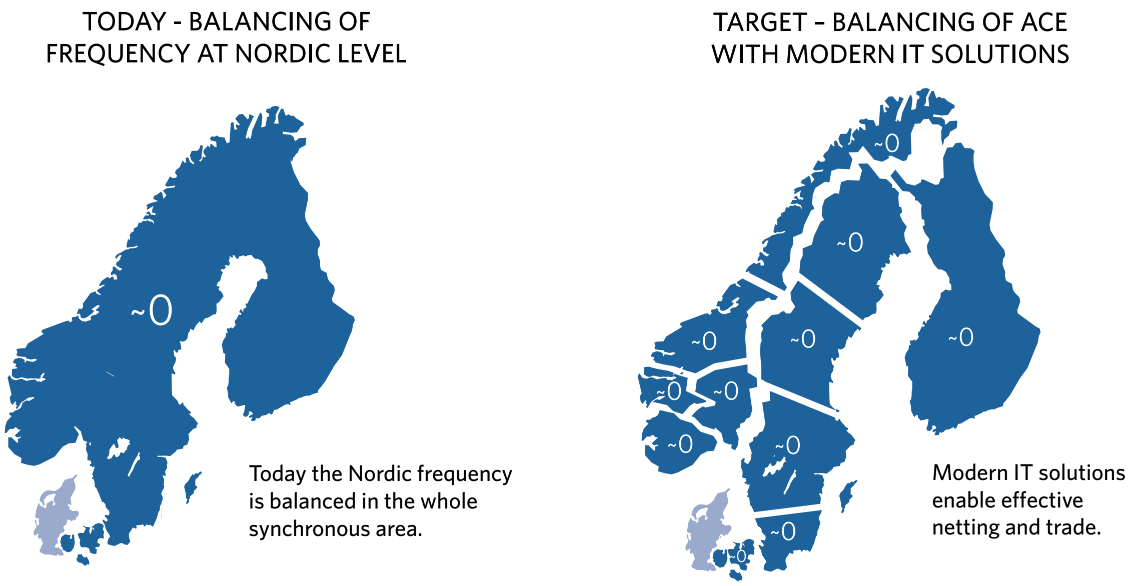


Figure 10. Frequency-controlled balancing at a Nordic level today and a transition to Modernised ACE Control (MACE).

purpose of a short trading and imbalance settlement period is to achieve a more accurate pricing of flexibility.

> To ensure the balancing in each bidding zone, dimensioning requirements are applied according to the system operation agreement and exchange of balancing capacity between bidding zones. This can when necessary and efficient be ensured by reservation of transfer capacity.

> The TSOs in the LFC block establish a common balancing market with functions for procurement and activation of balancing services. This is made possible by the TSOs adapting and harmonising the regulations, but a fully integrated balancing market also requires common platforms and IT support.

The new balancing concept also means a transition from a frequency-controlled balancing at a Nordic level to Modernised ACE Control (MACE). This means that the LFC block is balanced by taking into consideration the area control error (ACE) in the respective bidding area. The area control error is a measurement of the instantaneous imbalance and is calculated by comparing measured flows with planned flows on all area borders, taking into consideration the activated FCR. The area error can be calculated per bidding area or nationally and the sum of all ACEs in a synchronous area corresponds to the frequency deviation. On top of ACE, there are powerful modern IT solutions to enable effective netting and trade. Netting means that the TSOs avoid simultaneous activation of balancing services in opposite directions by allowing conflicting imbalances in different areas to cancel each other out.

The new concept gives several positive effects. All activation and netting of reserves regarding FRR will be provided from one bidding area to another. A more exact settlement of all activation is thereby enabled compared with today's control structure. It will be possible to settle activation in opposite directions within the same settlement period and it will also be possible to separate activation of different ancillary services with different prices. An important prerequisite in the new control structure is that it is possible to ensure access to resources in all areas. Dimensioning of reserves thereby becomes possible and the possibility for reservation of transfer capacity becomes an important tool.

6.3 Development of the various parts of the balancing process

The balancing process can be divided into three main sub-processes:

> System design and development are about ensuring a correct design of the operational centre's tools by specifying balancing and ancillary services, dimensioning and reserving transfer capacity, and market design.

> Planning and operation focus on the operational centre having the right conditions to make the right decisions and tools and methods to activate available resources in an operationally safe and socio-economically efficient manner.

> The settlement should result in a good cost allocation that creates the right incentive for the market's participants based on the principles that the market design has formulated.

The development initiatives in the various sub-processes for balancing are described in the following sections.

Tools/ancillary service

	INERTIA[16]	FFR	FCR: FCR-D	FCR: FCR-N	aFRR	mFRR	RR
Controlled by:	–	Frequency	Frequency	Frequency	ACE	Operational centre	Operational centre
Manages:	Capacity	Capacity	Capacity	Capacity	Energy	Energy	Energy
Economic compensation for:	–	Capacity	Capacity	Capacity/ Energy	Energy	Energy	Energy
Activated within:	Instantaneous	Up to one second	Seconds	One minute	Minutes	12-15 minutes	> 15 minutes

Activation, fast to slow

Today

Possible solutions

Figure 11. Tools and ancillary services for balancing of the future power system. Blue indicates possible solutions. [16]

6.3.1 System design and development

System design and development can be seen as a long-term sub-process of the balancing process. There, it is ensured that the operational centre has relevant tools by specifying ancillary services, dimensioning and reserving transfer capacity, and further developing the market design. Below, both planned and possible measures that concern this sub-process are presented.

Changes in ancillary services

The balancing in the future power system sets higher requirements on ancillary services and the total performance that needs to be delivered by future ancillary services must be specified. Initially, there is a need to improve coordination of current ancillary services to ensure the balancing and the purpose of the ancillary services.

The handling of ancillary services will in the future need to be more dynamic by procuring different volumes based on the operating situation. Strategies and tools will therefore be developed to streamline and ensure the right volume of reserves.

The purpose of the ancillary services is that FCR handles sudden imbalances; aFRR handles non-forecasted energy imbalances in the operating quarter and restores FCR; mFRR handles forecasted energy imbalances in the next operating quarter and restores aFRR; RR handles forecasted energy imbalances further ahead in time and restores mFRR. In addition to the existing ancillary services, it may be relevant to introduce new faster ancillary services (FFR). No decision has been made currently on the introduction of this kind of service.

The stochastic instantaneous imbalance that arises during operation is difficult to reduce and is instead something that the balancing service aFRR will handle. A larger permitted frequency range would provide more room for balancing and the use of inertia. Such an increase would also enable more FCR-N reserves to be procured. On the other hand, the system can be balanced in a better way by existing reserves being restored more efficiently or through a more rapid reserve. A more efficient restoration of the FCR-N reserve provides more space for variations and a faster reserve would primarily contribute to less regulation work to rapid variations for FCR-N units. More efficient restoration will take place when the right volume of aFRR exists, which needs to be coordinated with the new balancing strategy with MACE control.

Svenska kraftnät needs to investigate that an appropriately permitted frequency range is used in normal operation and further develop qualitative measurements for the frequency range. The quality measurement will be set in relation to the operational reliability targets and future operating conditions.

In the new Nordic balancing concept, aFRR will have a more prominent role in the future. In the target model, aFRR is mainly used as an ancillary service for the balancing of a measured imbalance during operation while the main function for mFRR is to satisfy the proactive balancing prior to operation. Due to its longer activation time, the balancing service mFRR is more suited to slower processes, but at the same time a proactive use enables a larger energy exchange on the European platform for mFRR.

Dimensioning of reserves

A correct dimensioning of ancillary services makes it possible for operational security and security of supply in the power system to be maintained in a cost-effective manner. The various ancillary services collaborate and interact, see Figure 11, which means that the process and principles for the dimensioning of an individual service need to take into consideration how other ancillary services are dimensioned. It thereby becomes more accurate to speak of a portfolio of services that are specified and dimensioned jointly.

As the power system is changing, among other things regarding the generation mix and degree of market connection of

16. For system inertia, no economic compensation is given However, system inertia is an ancillary service that counteracts frequency changes and thereby contributes to the power system's stability.

balancing markets in the Nordic region and Europe, regional and national balancing needs are also changing. One concrete example is the close relationship between FCR-N and aFRR. Both of these services are currently designed to be mainly used in the normal frequency range and a coordination of the dimensioning can provide benefits in the form of optimisation.

With the aim of updating the holistic view that is needed for an optimal dimensioning of ancillary services in the future as well, intensive Nordic work is under way in a number of projects and initiatives. However, it can be pointed out that dimensioning is a continuous effort.

As mentioned above, aFRR will have a more prominent role in the future and be used as a main ancillary service for balancing upon measured imbalance during operation and must then be dimensioned according to this. In addition, the relationship to inertia and FCR-N must be taken into account. The primary function for mFRR is to satisfy the proactive balancing for operation. In addition to this, the dimensioning needs to ensure adequate reserves for the handling of the dimensioning incident and internal bottlenecks in the electricity grid.

An important part of the dimensioning process is to also take into account the possibilities of sharing reserves between bidding zones and between countries. Here, the national responsibility for the balancing capacity must also be weighed in. The details for the dimensioning principles for FRR are investigated further in the scope of the Nordic system operation agreement.

Rapid Active Disturbance Reserves

Svenska kraftnät must always ensure that the system can handle new disturbances and it is therefore important to be able to quickly restore FCR-D when they have been used through the balancing service mFRR. This is done in Sweden and the Nordic region through the rapid active disturbance reserves. This also has the aim of quickly restoring the flows in the grid within current limits if a disturbance has led to overloads. In the Nordic system operation agreement (SOA), the Nordic TSOs have set requirements on how much fast active disturbance reserves the various countries shall provide. Today, Svenska kraftnät has ensured access to a necessary amount of fast active disturbance reserves through a number of long-term agreements with owners of a total of 22 gas turbines in the bidding zones SE3 and SE4 with a total installed capacity of 1,358 MW. Of this, 690 MW is owned by Svenska Kraftnät Gasturbiner AB, which is a wholly owned subsidiary of Svenska kraftnät.

The regulating power market is comprised of voluntary up or down regulation bids and situations therefore arise when there is not enough volume of mFRR bids to restore the automatically activated reserves. Svenska kraftnät therefore also has need of ensuring the supply of disturbance reserves through agreements. In case of a disturbance, available bids on the regulation power market are always activated first, followed by the disturbance reserves. When the total available amount of power from the contracted fast active disturbance reserves is below the current dimensioning incident, Svenska kraftnät compensates this by reserving transfer capacity equivalent to the deficit over Cut 2 (SE2-SE3). In order to minimise the impact on the electricity market, Svenska kraftnät strives for these reservations of transfer capacity to ensure the supply of fast active disturbance reserves to take place to the least possible extent.

In addition to the direct disturbance-related functions of the fast active disturbance reserve, the contracted gas turbines also contribute to other socially important and electricity preparedness-related functions. They have a critical role in the power system's possibility to be restarted after extensive grid failures and therefore constitute an important part of Svenska kraftnät's strategies for operations restoration. Gathering these benefits in a common procurement has been the most socially beneficial solution to ensure the long-term fast active disturbance reserves with the least possible impact on the electricity market.

In the network codes (GL SO and GL EB) and in Article 54 of the European Commission's recently presented "Clean Energy Package", there are requirements that could mean that Svenska kraftnät in the future cannot combine several benefits in the way that has been done in the procurements of the gas turbines in the disturbance reserve. The mFRR capacity needed to handle disturbances must be distinguished from other benefits and procured in a transparent marketplace where all resources that meet the requirements have the possibility to participate. For example, it is fully possible that the part of the fast active disturbance reserve that serves as mFRR could just as well consist of demand response as of gas turbines. This marketplace does not exist in Sweden today.

Svenska kraftnät is now beginning an effort to ensure that the future fast active disturbance reserve will be able to comply with the requirements set in the network codes at the same time as maintaining operational reliability.

Reservation of transfer capacity

In Europe as well as the Nordic region, a development is under way towards a greater regional exchange of balancing energy. This is something that is also encouraged in the European Commission's "Clean Energy for All Europeans" package of measures where it is emphasised that regional exchange in the electricity market among other things benefits the European end consumers in the form of lower electricity prices and a higher security of supply. Reservation of transfer capacity for balancing energy is mainly motivated by increases in socio-economic welfare and that it is needed to enable the expansion of a common Nordic and European market for balancing services. In addition, transparent and clear methods for reserving transfer capacity create a more formalised regional exchange of balancing energy at the same time that overloading of the electricity grid can be avoided.

Reserving transfer capacity for regional exchange of balancing energy means that a lower capacity is allocated to the day-ahead market or the intraday market, which in turn will lead to a lower electricity market benefit. The benefit of reserving capacity for exchange of balance energy should therefore always be weighed against the reduced capacity allocation.

Svenska kraftnät's position is that reservation of transfer capacity for regional exchange of balancing energy is motivated

17. Energy Commission's final report , SOU, 2017. Kraftsamling för framtidens energi – Betänkande av Energikommissionen, Stockholm: Statens Offentliga utredningar SOU 2017:2.

if it is socio-economically profitable, i.e. that the benefit of using the capacity in the balancing market is greater than the benefit of using the day-ahead or intraday market. More specifically, it is justified to reserve transfer capacity for balancing energy if the price difference on the balancing market between the different bidding zones for which the exchange takes place is greater than the expected price difference in the day-ahead market.

Demand response in the balance regulation

The development of the European electricity market is going in a direction where the need for active demand is becoming increasingly clear. Demand response is also an important piece of the puzzle in the handling of the future balancing challenges. There is today a clearly-stated ambition both in Swedish energy policy[17] and in the work on harmonising the European electricity markets, to minimise the market-based obstacles for an increased amount of demand response.

The concept of demand response includes many kinds of resources where electricity consumption, depending on some form of external signal, changes and/or shifts over time. This may be (individual or aggregated) electricity consumption in, for example, households and industries. The characteristics of these vary widely as regards capacity, repeatability, endurance and speed, which mean that they are suitable for various types of balancing. It is therefore important that the formulation of market structure and ancillary services is compatible with demand response. The balancing market should also be technology-neutral and non-discriminatory so that various types of resources have the possibility to participate at the same terms. Today, there is therefore a need to make the rules technology-neutral and eliminate the barriers that exist for actors to be able to participate with electricity consumption as a reserve. Current descriptions and regulations for participating in the balancing market are formulated based on the conditions for hydro power. Svenska kraftnät's settlement of primary and secondary control is also adapted based on generation resources.

Aggregation is seen as an important opportunity for demand response, where the electricity users' capability to adapt their consumption is packaged and, for example, bid on the balancing market. Depending on how the regulations for aggregation are formulated, several benefits can be achieved. In general terms, the benefits are based on the possibility to bring together many small and passive electricity users' capability into larger and actively available flexibility bids. In several European countries, the market's regulations have therefore been adjusted to facilitate a new market participant, the aggregator. The European Commission is now also discussing, within the scope of the "Clean Energy for All Europeans" package, the manner in which equivalent legislation should be formulated at a European level.

Large parts of the demand response that originates from individual small electricity users in aggregated form, service sector or industry, can contribute through automatically controlled regulation where the frequency represents the control signal. It is of major interest to Svenska kraftnät to enable greater competition. At present, the automatic reserves consist solely of hydro power, mainly in SE1 and SE2 (> 90 percent). An

PHOTO: TOMAS ÅRLEMO

introduction for new types of reserves such as demand response would increase the currently limited number of bidders in the procurement of automatic reserves. It should also enable access to automatic reserves in areas where these do not currently exist, such as in SE4. Another conceivable benefit of having demand response in the markets for manual and automatic (frequency-controlled) reserves is that capacity in hydro power is released and that the combined regulation capacity in the power system increases.

To evaluate the aggregation of demand response, Svenska kraftnät has conducted a pilot project called "Flexible households" ("Flexibla hushåll") where water heaters in around 100 homes were aggregated and offered on the market for primary control (FCR-N). The results of the final report[18] show that the water heaters could contribute to balancing the power system. The control of the water heaters followed the variations in the frequency well and demand response was activated quickly enough to meet the technical requirements for FCR-N. At the same time, there were challenges in meeting the technical requirements for the reporting of measurement values to Svenska kraftnät's operational monitoring system. There were also challenges in achieving the requirement of minimum bid size with the number of test customers that participated in the pilot project and it would be necessary to have a larger number of water heaters than those that participated in the test to provide sufficient capacity with adequate endurance. The pilot project has contributed to clarifying what adaptation needs exist in IT systems and regulations to enable a broad commercial introduction of aggregated demand response in frequency regulation.

18. Svenska kraftnät (2017): Slutrapport pilotprojekt Flexibla hushåll (Svk 2016/1688)

Svenska kraftnät is now continuing the work of investigating how the conditions for automatic reserves from the consumption side can be promoted in various ways; among other things, Svenska kraftnät has announced a new pilot project and is developing a strategy for how the necessary market changes should be implemented. According to the current timetable, a new pilot project regarding demand response for FCR-D will be started during the first quarter of 2018.

6.3.2 Planning and operation

Planning and operation can be seen as another sub-process of the balancing process. This sub-process focuses on the operational centre having the right conditions to make the right decisions, and the tools and methods to be able to activate available resources in an operationally safe and socio-economically efficient manner. Below, both planned and possible measures that concern this sub-process are presented.

Work in the operational centre

The work carried out by the personnel at Svenska kraftnät's balancing service consists mainly of performing manual regulations, with the aim of maintaining the Nordic power system's security of supply and frequency quality, and restoring the power system to a state of operational reliability after any disturbances that may occur. In concrete terms, the work is based on using manual regulations to:

> Free the system's automatic reserve capacity (FCR-N, FCR-D and aFRR), after this is used for system imbalances that occur.
> Control flows on the power system's transmission power lines so that they do not exceed current limits.
> Manage disturbances and stressed operating situations.

Together, they constitute the two first working tasks of the so-called balancing regulation. In purely physical terms, the balancing regulation is based on controlling the power system's balance at an aggregated (frequency regulation) and a local system level (regulation of flows) by adjusting generation and consumption, as well as import and export.

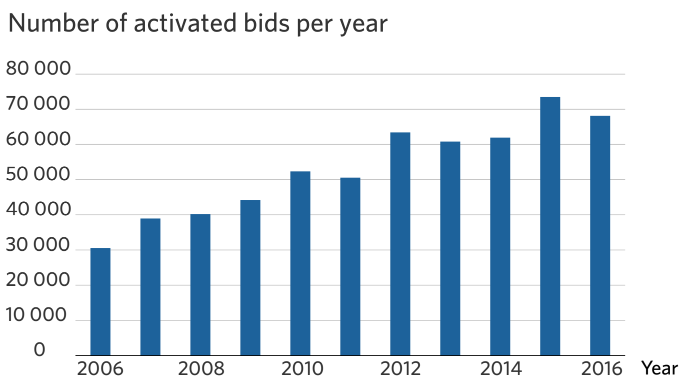


Figure 12: Number of bids per year for up and down regulation that have been activated by Svenska kraftnät's balancing service during the years 2006-2016.

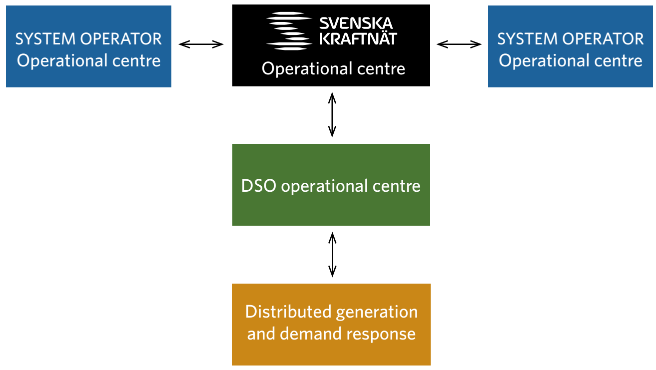


Figure 13: Greater need for coordination between Svenska kraftnät's and other grid and system operators' operational centres.

Greater challenges for the power system control

The large amount of wind power entering the power system in recent years has contributed to the balancing regulation becoming increasingly complex and challenging. Other trends that have also affected the conditions for balancing regulation are, for example, a greater interconnection and market integration with neighbouring power systems. The increased complexity and growing challenge for Svenska Kraftnät's balancing service come from the imbalances in the power system having a new and increased dynamic, changed predictability, and a changed geographic distribution. The size and variation of the imbalances have also changed. This is illustrated in Figure 12 in the summary of the total number of bids (mFRR) that Svenska kraftnät's balancing service has activated in the past ten-year period.

The operations personnel in Svenska kraftnät's operational centre activated more than twice as many bids in 2016 than ten years earlier. Considering the energy policy objectives that exist on both a Swedish and European level, it is highly likely that the balancing regulation will become even more demanding in the future.

The transition in the power system means that the future's normal operating situations will become even more complex than today. At the same time, the operating cooperation will set higher requirements both on the international level to other European TSOs as well as to DSOs in Sweden. Svenska kraftnät's operational centre, which is in the middle of the development towards both centralisation and local challenges, is gaining an even clearer key role in the daily operations. In Figure 13, on-going changes are described through two different flows that will have a major impact on the operational centre's operational activities.

The connections on the horizontal level describe the growing cooperation and the integration between the transmission grid's and the TSO's operational centres that will be required for European harmonisation.

The vertical level depends on greater connection to regional and local grid operators. This is driven by the on-going deve-

PHOTO: TOMAS ÄRLEMO

lopment towards a more decentralised electricity generation, a rising share of microgeneration and demand response that will lead to changed power flows. With a changed consumption pattern and an increased amount of decentralised generation at lower voltage levels, subsystem operators are forced to handle new types of operating situations. In an increasing scope, they will need to implement regional balancing to handle bottlenecks or capacity shortage in their grids. This also means that capacity needs to be procured to ensure that necessary resources are available locally where they are needed. Regardless of which solutions are chosen, it is unavoidable that greater coordination with Svenska kraftnät's operational centre is needed.

Svenska kraftnät and the national operational centre is not just faced with challenges that a more complex normal operation will lead to. It is just as important that expertise and readiness exist for handling consequences of disturbances that arise or in the worst case a restoration of the grid after a major disturbance.

Measures to improve the operational centre's conditions
As balancing becomes more challenging, several types of measures will be required, not least to improve the operational centre staff's options for maintaining an accurate and satisfactory view of the status of the power system. These can be divided into four main areas:

> Access to information and an increased collection of real time measurements. The collection does not only cover measurements from Svenska kraftnät's facilities, but also measurements from generation facilities, underlying regional grids and other European grid operators.
> New working methods that are adapted to changing conditions and require electronic activation and an expanded share of automatic reserves.
> Improved coordination with the subsystem operators for regional grids.
> Improved IT solutions that are adapted to new needs to visualise events is a prerequisite for the operator to be able to quickly understand the operating situation and initiate correct balancing measures.

Nordic and European FRR platforms
As mentioned above, a harmonisation of the balancing market is under way at a European and Nordic level. A concrete example is that the European TSOs shall establish platforms for the exchange of balancing energy according to GL EB. GL EB prescribes, among other things, platforms for the balancing services mFRR, aFRR and RR and that all system operators that use the respective balancing service shall connect to the platforms. The European FRR platforms will also manage the settlement between TSOs.

The platforms enable market coupling of balancing markets and Svenska kraftnät is deeply involved and sees socio-economic gains in expanding the balancing markets. At the same time, GL SO sets requirements for certain functions related to FRR being placed locally for every synchronous area, LFC block and LFC area. In addition, the fact that important balancing functions are placed on European platforms results in stringent demands that a robust Nordic IT platform (fall-back platform) is created to ensure operational reliability.

In accordance with the long-term strategy for the balancing of the Nordic power system, the process for the activation of

FRR bids will be a part of the control of the area control error (so-called MACE control) for the respective LFC area. According to the strategy, mFRR shall be activated mainly proactively and aFRR reactively. The strategy is long-term and it can be assumed that there will be a need within the foreseeable future to also activate mFRR for reactive purposes, such as in unforeseen variations or errors in generation facilities or the grid. For these activations, a Nordic function will be needed.

The process for aFRR is a fully automated balancing process with the aim of minimising the area error in each bidding area. For balancing in the normal case, aFRR will in the long term be the main tool for reactive activation in the Nordic region.

Information to the market participants

Stricter requirements are being applied to the electricity market participants to publish information. As system operators, this includes publishing information on the balancing status closer to real time, which is stated by GL EB. Among other things, TSOs shall publish information on the system balance no later than 30 minutes after real time. In addition, every system operator shall publish information on bids, anonymised if necessary, no later than 30 minutes after the completed market time unit regarding, among other things, the type of product, volume and price. This shall take place no later than two years after GL EB entered into force, which according to the current timetable is during 2019 since GL EB is expected to enter into force in 2017.

Depending on what information is published, it creates different possibilities for the market participants to act. More information closer to real time can potentially create clearer incentives for the market participants to act and thereby reflect actual imbalance prices. At the same time, there are risks in the form of potential overloads in the grid in the event that information on the system's imbalance makes many participants quickly move in a certain direction. It is not necessarily so that the electricity grid is able to accommodate many participants moving in a certain direction at short notice. In addition, it is important to take into account how publication of information closer to real time can affect the market participants' conditions to compete with each other. The competition between participants must not be distorted. A shorter settlement period can, however, conceivably resolve the aforementioned problems.

Svenska kraftnät is essentially positive to providing the market with information closer to real time if it can create clearer price signals and better reflect the real-time value of balancing power, as long as the grid load and thereby the security of supply is not put at risk.

6.3.3 Settlement

A third sub-process within the balancing process is settlement. This sub-process ensures that the costs are distributed in a way that creates incentives for the market participants according to the principles formulated for the electricity market. Both planned and possible measures that concern this sub-process are presented below.

The length of the imbalance settlement period

Today, Sweden, like the rest of the Nordic region, applies an imbalance settlement period of 60 minutes. The imbalance settlement period is the period of time for which the BRP according to its agreement with Svenska kraftnät (Balance Responsibility Agreement) shall fulfil its balancing responsibility by continuously planning for and commercially achieving a balance between its supply and its demand for electricity. The BRP is financially responsible for arising imbalances which is why the length of the imbalance settlement period is a fundamental design parameter in the settlement of imbalances. The imbalance settlement period's length also affects the design of the balancing market as well as the trading period on intraday trade. By extension, the trading period for the day-ahead market is also affected.

Due to its profound impact on the market's structure, a harmonisation of the imbalance settlement period's length is a central objective in the European integration work. Through GL EB, a common 15-minute long imbalance settlement period is therefore being introduced no later than three years after the guideline has entered into force. Exceptions shall only be able to occur during a limited time through the transmission system operator's application and the supervisory authority's approval. Within the scope of the European Commission's package "Clean Energy for All Europeans", the legal framework is also supplemented by the trading period for the intraday and day-ahead trade becoming 15 minutes no later than 2025.

In addition to a harmonised period length, Svenska kraftnät also sees advantages with choosing a shorter period than the current 60 minutes. A 15-minute imbalance settlement and trading period enable a more accurate pricing of flexibility since the price of balance energy and imbalance energy is allowed to reflect the real-time value of energy to a greater extent. In addition to this, operative benefits are also realised, such as structural imbalances being reduced.

Svenska kraftnät is therefore positive to a harmonised and shorter imbalance settlement and trading period and sees it as an opportunity for a more effective balancing model. During the spring of 2017, Svenska kraftnät implemented together with the other Nordic TSOs a cost-benefit analysis of how the shorter imbalance settlement period (15 minutes) can be best introduced in the Nordic region[19]. The costs are mainly of a non-recurring nature linked to the actual implementation (such as changes in systems for measurements and settlement) while the benefits connect to long-term market and operating values, such as e.g. clearer price signals, better conditions for trade with other countries and reduction of structural imbalances.

The Nordic cost-benefit analysis also includes an initial overall implementation plan that proposes an introduction date in 2020. In autumn 2017, Svenska kraftnät began the work of refining the timetable and preparing the implementation in cooperation with the market's participants and the other Nordic TSOs.

Settlement of imbalances

In addition to a shorter imbalance settlement period, GL EB also will lead to harmonisation of several other parts of the imbalan-

19. Svenska kraftnät et al. 2017: Finer time resolution in Nordic power markets: A Cost Benefit Analysis

ce settlement where the number of positions and the calculation of the imbalance price are among the most central. Instead of two positions per BRP and bidding zone – one for generation and one for consumption – a common position is expected to be introduced. In addition to this, the current two-price settlement for generation is planned to be replaced with a model based on a one-price settlement even if two-price settlement can still be applied under certain circumstances. The circumstances under which this can take place are still subject to European model development.

Svenska kraftnät sees both advantages and challenges with the European target model for imbalance settlement. One position and one-price settlement simplifies aggregators and creates incentives for supporting the system balance. At the same time, there is a risk that the incentives to follow the generation plan may be weakened, which can become an operational challenge. The changes in imbalance settlement therefore needs to be supplemented with an appropriate regulatory framework to publish information for participants as well as balanced incentives for self-regulation.

Settlement of activated balance energy between TSOs

Settlement between TSOs is divided by GL EB into intended and unintended exchanges of energy. Intended exchange is defined as the exchange of balancing energy in the form of balancing services, typically European standard services for FRR and RR or other possible regionally defined balancing services. Principles for pricing and settlement between TSOs shall in this context be established at a European level and it is the European platforms that will handle the settlement functions for the standard services. Within the work on the future Nordic balancing model, it is proposed that the balancing energy exchanged between TSOs shall be settled against the marginal price. This is also in line with the European target model.

"Unintended exchange" is indirectly defined according to GL EB as energy that is not a result of intended exchange. Principles for settlement of "unintended exchanges" shall, according to GL EB, be developed by all TSOs within a synchronous area. This work will be initiated in the Nordic region and a proposal shall be presented in 2019.

The European regulations for settlement of energy exchange between TSOs differ fundamentally from the principles that are currently applied in the Nordic region and the implementation of GL EB thereby will lead to major changes.

The Nordic project Full Cost Balancing

With the aim of implementing the legal framework for imbalance settlement that the European legislation constitutes and identifying possible routes to develop the Nordic imbalance settlement, the Nordic TSOs implemented a common project called Full Cost Balancing in spring 2017. The project resulted in a number of possible changes that Svenska kraftnät together with its Nordic equivalents will use as a basis for continued work. In summary, the following is proposed:

> The most expensive activated bid in the balancing market that counteracts the system imbalance sets the marginal price. This applies regardless of product, i.e. independent of whether or not it is a bid for aFRR, mFRR or a possible future balancing service such as RR.
> The balancing service provider (BSP) is always compensated according to the marginal price regardless of the reason for activation. The bid areas without transmission limits between them receive the same marginal price.
> Shortage of available balancing resources reserves is reflected in the imbalance price in a clearer way than today.

PHOTO: TOMAS ÄRLEMO

The proposals differ from the current procedure where the imbalance price is calculated based on the marginal price for mFRR. When the volumes for the balancing energy from other balancing services, such as aFRR, increase, the value of this energy should also be shown in the imbalance price. The proposals also entail a new definition of the pricing of special regulations.

Svenska kraftnät's main objective is to evaluate various possibilities for more accurate price signals being created by the balancing market (including the balancing settlement).

7. DAY-AHEAD AND INTRADAY MARKETS

SUMMARY

The majority of physical electricity trade in Sweden takes place on the day-ahead and intraday markets. To obtain an effective market-based balancing of consumption and generation of electricity, these markets need to have access to sufficient transfer capacity and generation capacity. In recent years, generation capacity has been increasingly in focus due to the transition of the electricity market towards a larger share of intermittent generation, less baseload generation and other planned generation. The development is clearly moving towards a situation where the risk of power shortages is increasing and various measures are needed to handle this. Svenska kraftnät is not responsible for ensuring generation adequacy, but nonetheless contributes indirectly to strengthening this by, for example, building cross-border interconnections to strengthen the connection to the European power system. Examples of other measures that indirectly increase generation adequacy are:

> Together with the other Nordic TSOs, Svenska kraftnät has proposed the implementation of a flow-based capacity calculation method. This method creates the market flows that better represent the physical flows compared with today's method. This method is expected to be implemented no earlier than 2020.

> The implementation of an in-depth European integration in the intraday market (XBID) is an important part of creating market solutions that support a power system with a larger share of renewable capacity. XBID is expected to increase the possibilities of market actors to use trading as a tool to maintain their balance and the new solution is planned to be implemented in 2018.

> In the next winter period 2017/2018, the strategic reserve will be priced according to the price cap in the day-ahead market. Price formation in the day-ahead market is thereby less affected and the Swedish and Finnish regulations are harmonised. Moreover, it is in line with future regulations that prescribe clearer price signals, which promote flexibility and thereby strengthen the power system's adequacy.

The majority of physical electricity trade in Sweden and the rest of Europe takes place on the day-ahead and intraday markets. The day-ahead market is the main place for electricity trade where buy and sell bids are matched for hourly delivery of electricity for the coming day. The pricing is controlled by supply and demand and any transmission limitations in the electricity grid. The intraday market is a complement to the day-ahead market where market participants can use trading as a tool to maintain their balance. Trading takes place continuously until one hour before the operating period (today equivalent to the "operating hour"). Today, the turnover on the intraday market is small compared to the day-ahead market. At the same time, Svenska kraftnät sees that the intraday market is gaining an increasingly important role with the increasing share of intermittent generation. European market coupling on the day-ahead and intraday markets is being developed at a rapid pace, which result in larger markets regarding geography as well as liquidity. The development is highly driven by GL CACM and Svenska kraftnät is deeply involved in the work with its implementation.

7.1 Adequacy

The power system's adequacy can be described as its ability to meet the electricity needs of electricity consumers. Adequacy is needed both regarding grid capacity and generation capacity. Generation capacity has become an area that has received more focus with regard to adequacy in recent years. A structural transformation is occurring within the electricity market towards a larger share of intermittent generation, less baseload generation and other dispatchable generation. At the same time, low electricity prices result in poor profitability and worse conditions for investments in new generation capacity. The electricity market's ability to create incentives for sufficient power to be available in the power system has therefore begun to be called into question. It is, however, not within Svenska kraftnät's responsibility to ensure generation adequacy.

7.1.1 Generation adequacy

The power system's development up to 2040 is expected to lead to Sweden having a continued positive energy balance on

PHOTO: TOMAS ÄRLEMO

an annual basis. With a larger share of intermittent generation, however, the number of hours with power shortage is expected to be many, mainly in southern Sweden, which will lead to a major challenge to the adequacy in the power system.

To reduce the risk that situations with power shortages arise, Svenska kraftnät has procured a strategic reserve within the scope of the Act on Strategic Reserves[20], which applies until 2025. According to the law, the power reserve shall be created by the system-responsible authority entering into agreements with power producers to make additional generation capacity available as well as entering into agreements for reduced electricity consumption. The strategic reserve thereby contributes to an improved generation adequacy. The strategic reserve shall be available between 16 November and 15 March.

In a situation where not even the supplementary capacity ensured through the strategic reserve is enough to meet demand, Svenska kraftnät may need to order disconnection of consumption to handle the balance in the power system.

7.2 Development projects for greater adequacy

Even if it is not within Svenska kraftnät's responsibility to ensure generation adequacy, Svenska kraftnät conducts measures within its area of responsibility, which contribute to "promoting an open Swedish, Nordic and European market for electricity". Many of these measures contribute to strengthening generation adequacy even if it is not their primary purpose. Several measures and projects are planned that are expected to strengthen the power system's adequacy.

The expansion of the transmission grid is one example of how Svenska kraftnät is strengthening grid capacity. Local power shortage can be resolved through grid expansion if there is sufficient generation in the system but it cannot be used due to limitations in the transmission system. New transmission connections to other countries enable greater imports in the event of shortages, provided that there is surplus power in the exporting regions. This also depends on the capacity in the internal grid of the exporting region and that the transmission connection is in fact available.

As for generation capacity, Svenska kraftnät also conducts additional measures besides grid reinforcements to strengthen the power system's adequacy. Many measures are related to the design of the electricity market, which means that they are carried out in association with the other Nordic TSOs. In a report prepared by the Nordic TSOs[21], several important changes are presented that will affect the future design of the electricity market and related ancillary services:

> Finer time resolution in the electricity markets: by introducing a higher time resolution in the electricity markets, the structural imbalances are expected to decrease, which frees reserve capacity.

> The Full Cost Balancing project: this project aims to create further incentives for BRPs to be in balance by exposing them to the actual cost of imbalances. In turn, this contributes to adequacy by promoting flexibility.

> Common Nordic capacity calculation method: a common Nordic capacity calculation method is expected to maxi-

20. Act (2003:436) on Strategic Reserves
21. Svenska kraftnät et al. report 2017: Generation Adequacy – market measures to secure it and methodology for assessment

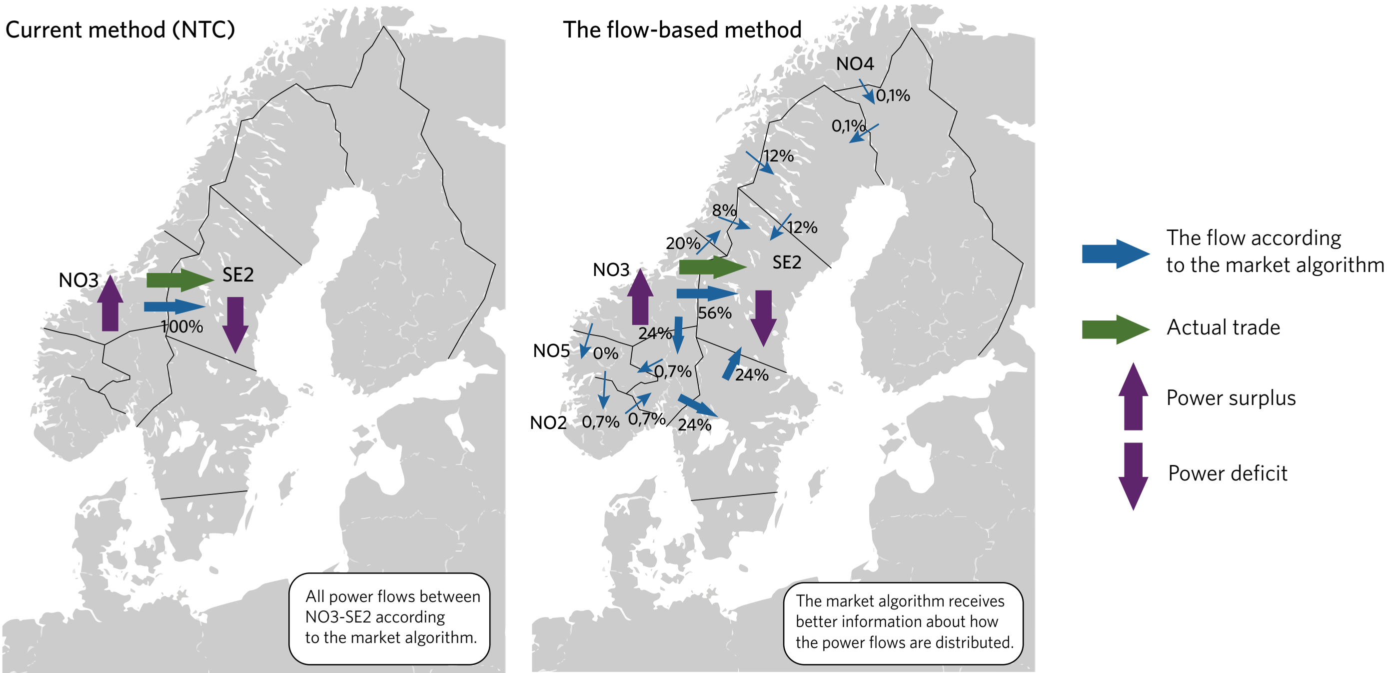


Figure 14. Illustrative example that shows how the flow-based method (right-hand figure) differs from the current method NTC (left-hand figure). The example shows the flow between bidding zones SE2 and NO3.

mise the benefit of the electricity grid and the possibility of following up regional challenges regarding adequacy.

> Strengthening the role of electricity consumers: by introducing new technology solutions and services in the electricity markets, electricity consumers can among other things be given the opportunity to benefit from the potential flexibility that exists in their consumption.

Besides these changes, Svenska kraftnät is working on three projects related to the day-ahead and intraday markets which contribute to strengthening adequacy in the power system.

7.2.1 Changed capacity calculation methods

The day-ahead and intraday markets provide effective matching of consumption and generation of electricity, whilst taking into account the transfer capacity in the electricity grid. The electricity grid has a certain collective capacity to transmit electricity and its relevant physical limitations need to be calculated, simplified and communicated to the electricity market to ensure operational reliability in the power system. The method for this calculation is called the capacity calculation method.

According to GL CACM, the flow-based method shall apply as the capacity calculation method in all Member States in the EU, unless the affected TSOs can show that an application of the method for coordinated net transfer capacity (C-NTC) is more effective.

In light of this, Svenska kraftnät and the other Nordic TSOs have worked on a project to assess the advantages and disadvantages of introducing a flow-based method for capacity calculation in the Nordic countries. In the project, market simulations have been done, among other things, to compare the flow-based method with the current capacity calculation method. In addition, the project has worked to develop a method for coordinated net transfer capacity. The results in the project indicate that the flow-based method will lead to a higher social benefit for the Nordic electricity market compared with today's method (NTC).

Svenska kraftnät proposes together with the other Nordic TSOs to implement flow-based capacity calculation in the day-ahead market and C-NTC as an interim solution in the intraday market. A flow-based capacity calculation will lead to a market solution that better supports system operations. It creates market-based flows that better represent the physical flows than with today's capacity calculation method, as illustrated in Figure 14.

This method also takes into consideration the capacity for trade both within and between bidding zones, and also for bidding zones that are not adjacent. Flow-based capacity calculation is thereby expected to contribute in the long term to grid capacity being allocated so that it creates the most benefit.

According to the current timetable, the approved method will be implemented in the Nordic region in the day-ahead market no earlier than 2020. For the intraday market, the method that will be used initially is coordinated net transfer capacity since the IT solution implemented for the intraday solution does not support the flow-based method. No timetable can currently be given for when an implementation of flow-based capacity calculation is estimated to occur in the intraday market.

The flow-based capacity calculation method will potentially entail a more efficient use of the transmission grid. A consequence of this method is that price differences between bidding zones will probably arise more often, but will become smaller. This is because the method adjusts the prices in all bidding zones when a bottleneck arises somewhere in the Nordic system. As a result of this, all bidding zones will have different prices.

For Sweden, this means that a price difference may arise between Swedish price areas even though transfer capacity is not fully used. This occurs since there are other market flows happening at the same time that further increase the total Nordic social-economic welfare. Svenska kraftnät's overall assessment is nonetheless that the flow-based capacity calculation method is the best solution.

According to GL CACM, consideration shall be taken in the capacity calculation to capacity already reserved between bidding zones. Capacity can be reserved on interconnections for the transmission of ancillary services before the day-ahead market's capacity calculation and allocation. The reserved capacity means that less capacity can be allocated in the day-ahead and intraday markets.

With the method for coordinated net transfer capacity, reservation can be made directly on the relevant price area borders. However, this is not possible in the flow-based method since it considers how the power flow is distributed in the grid between different line segments. Therefore, reservation of capacity with the flow-based method needs to be directly related to the specific line segment affected and the bidding zones where the balancing energy shall either be produced or consumed. The reserved capacity on each individual line segment will be subtracted from the available capacity on each relevant line segment.

7.2.2 Market coupling on intraday

The intraday market is of central importance for market participants to be able to adjust their balance after the day-ahead trade is closed. With an increasing amount of intermittent electricity generation, the significance of the intraday market will also increase since the possibility for participants to adjust their balance due to changes in weather forecasts can then have a larger impact.

Svenska kraftnät has, together with 14 other TSOs and four electricity exchanges in Europe, been involved in the Cross Border Intraday (XBID) development project. It aims to deepen the integration between the electricity markets in Europe by establishing a common platform for cross-border intraday trade. The project is a part of implementing the requirements in GL CACM and the process is being carefully monitored by the European Commission.

By making cross-border trade also available on the intraday market, XBID can increase the possibilities for market participants to trade themselves in balance since they gain access to a larger market. The project can thereby contribute to creating better conditions for minimising imbalances before the operating phase, which frees up reserve capacity.

According to the current timetable, XBID will be launched in 2018.

PHOTO: TOMAS ÅRLEMO

7.2.3 Pricing of strategic reserves

Up to now, the strategic reserves that Svenska kraftnät has procured in Sweden have been priced at EUR 0.1/MWh above the highest commercial bid; this occurs when assessment shows there to be a risk that supply will not cover demand and a power shortage will thereby arise. Beginning in the period of 16 November 2017 to 15 March 2018, Svenska kraftnät will instead price the strategic reserve according to the price cap in the day-ahead market, which today is EUR 3,000/MWh.

The purpose of the change is to achieve several effects:

- The impact of the strategic reserve on the market is reduced.
- This regulation is harmonised with Finland, which also prices the reserves according to the price cap in the day-ahead market (the only other country in the Nordic region that also has a strategic reserve).
- This is in line with future regulations that require clearer price signals.
- Such pricing can contribute to more demand response being made available to the market.

8. GRID DEVELOPMENT

SUMMARY

Grid development is derived from four main driving forces:

> A major driving force for new investments in the grid is the connection of new electricity generation where the majority is comprised of wind power. The largest amount of wind power is expected to be connected in northern Sweden.

> The European market integration in combination with the connection of large amounts of intermittent electricity generation provides a greater need for connections between the Nordic countries and between the Nordic region and the continent.

> Large consumption increases in the metropolitan regions, driven by both general growth, but also specifically by data centres being established, lead to extensive network investments to secure the electricity supply for these areas. The location of additional production, combined with the closure of nuclear power and increasing consumption in southern Sweden, also increases the need for transfer capacity from north to south in the grid.

> Grid development is also driven by the need for reinvestments. The oldest parts of the Swedish grid are approaching the end of their technical lifetime and large parts of the grid will need to be renewed in the next few decades.

There are two major challenges to overcome in order to implement the necessary measures in time:

> Long lead times in the permit processes. Contributing factors to this are the deficiencies in general regional planning that do not take into account that, for example, the establishment of new residential areas or industries also will require reinforcements of the electricity grid.

> Many planned outages must be made on power lines in the transmission grid due to the new investments and reinvestments. These will lead to reduced trade capacity for the electricity market, which will have a detrimental socio-economic impact.

This chapter focuses on the grid investments that result from the various driving forces for the development of the grid. Even if it is not stated for each particular case, the choice of measures has been preceded by an analysis of how the needs can be met in the most efficient way. In many cases, it is clear that new power lines or substations must be built. In other cases, system-related measures and market measures are combined with grid investments to achieve the goal in the most efficient way. There is also often a mix of measures which have different time perspectives. For example, different system protection solutions or other kinds of operational measures may be used to temporarily increase capacity while the work of establishing a new line is under way. However, it is important that such solutions do not risk operational security in the system. Various types of grid investments are also considered before the final decision is made. If several smaller station measures can achieve the same results as a new line, the station measures together can then be the measure that Svenska kraftnät primarily chooses.

Svenska kraftnät has chosen to categorise the grid development projects into various different sub-portfolios based on the main driving forces behind them. One of the most important reasons for this is to be able to ensure internally that certain types of projects are not unintentionally deprioritised in favour of others, which concerns in particular the renewal of ageing facilities. The sub-portfolios that are now used are: connection of regional grids, market integration, system reinforcement and reinvestments.

8.1 Changes to the Network Development Plan 2016-2025

At the end of 2015, Svenska kraftnät published a grid development plan for the period 2016-2025. Since then there has been a number of changes in the grid development projects. The major changes that are of a more general interest are:

> Svenska kraftnät's board decided in May 2017 to end the work with the connection to Gotland that was previously planned. The main reason for this is that the socio-economic welfare assessment shows that the costs for the cable significantly exceed the various socio-economic benefits that it would bring.
> Svenska kraftnät and Fingrid have jointly decided to move forward with the third AC connection planned between the two countries. Svenska kraftnät's board therefore decided at the end of 2016 to carry out a technical feasibility study including preparatory permit work for the line on the Swedish side. The agreement between Svenska kraftnät and Fingrid also means that large parts of the cost on the Swedish side will be carried by Fingrid since the socio-economic benefits largely arise in Finland.
> The project to increase the capacity of Cut 1 is being shelved until further notice. The most recent analyses of Cut 1 and the need for a capacity in-crease indicate a smaller number of congestion hours and that the need will decrease as a result of the third line to Finland being built. According to previous analyses, the capacity in Cut 1 has been deemed to be able to increase from 3,300 to 4,500 MW by implementing series compensation in the power lines in Cut 1.
> The planning work for Hansa PowerBridge, a new connection between southern Sweden and Germany, is continuing. Svenska kraftnät's board took a decision in March 2017 that means that the application work for the necessary permits for the connection has now begun. Hansa PowerBridge is planned as an HVDC connection with 700 MW transfer capacity and is being developed in cooperation with the German grid operator 50Hertz. A final investment decision is expected to be taken at the end of 2022, which could lead to a commissioning of the connection in 2025-26.
> About 20 power lines have come so close to the end of their technical life-time that the work of renewing them will begin during the period 2018-2027. An overall system study has started to investigate how the renewal of these power lines can be implemented in the best way.

8.2 Driving forces for grid development

In the 1990s and early 2000s, there were few driving forces for investment in the transmission grid and investment levels were relatively low. Over the last decade, the situation has gradually changed. Today, a large number of forces are interacting to drive grid investments.

The change in energy and climate policy together with an ageing transmission grid represents the largest overall drivers of grid investments today and over the next decade. The transmission grid is expected to be expanded in line with developments in society so that political ambitions can be fulfilled without the grid being a significant limiting factor. Svenska kraftnät is now conducting several large projects that aim to meet these expectations; however, in one area, Svenska kraftnät has difficulty living up to these expectations today. In metropolitan areas, electricity demand is expected to increase significantly more quickly than the rate at which Svenska kraftnät is able to implement the reinforcements that are necessary.

The on-going and upcoming major changes in electricity generation and consumption mean that the electrical grids, including the transmission grid, need to be adapted to meet new needs. For example, the decommissioning of Swedish nuclear power will have a negative impact on the transfer capacity in the transmission grid unless equivalent reactive resources are installed. In addition to measures to increase transfer capacity, measures are also needed to maintain today's capacity. Large parts of the transmission grid are beginning to reach the end of their technical lifetime and the need for reinvestments is significant. Extensive measures in the transmission grid are therefore necessary to be able to meet future power needs.

By dividing the driving forces into four areas, it is possible to capture the various causes that lie behind the grid measures that Svenska kraftnät is implementing. The same division is also used for internal work to facilitate planning and man-agement of all on-going and upcoming projects. The various driving forces and their effect on the development of the transmission grid are described below.

8.2.1 Grid connections

Svenska kraftnät mainly connects grids of other grid owners to the transmission grid. These owners take on subscriptions for the generation and/or consumption of electricity fed in to/taken out from the transmission grid based on the generation and consumption connecting to their own grid. In several cases, such as large wind farms, direct connections are made to the transmission grid through a line separated from the other regional or local grids. Such a connection line is most often owned by a separate grid owner. To clarify the reasoning and causes for the connections that Svenska kraftnät works with, this section uses the expression "connection of wind power" even if this is formally not entirely accurate.

Connections of new or increased generation or consumption always require some sort of adjustments in the transmission grid. This applies to connections of both new wind power generation and larger electricity consumers such as data centres. These adjustments can consist of everything from minor adjustments in an existing substation to entirely new power lines and substations. By law, Svenska kraftnät has an obligation to connect generation and consumption unless there is a special reason to refuse to do so.

Connections during 2018-2027

Svenska kraftnät continuously receives applications for various connections to the transmission grid[22]. The total capacity in the applications for new connections to the power grid has previously increased steadily. The main reason is the expansion of wind power. Svenska kraftnät has, however, in the past two

22. Connection cases that have been investigated are included in the appendix "10-year network investment plan"

PHOTO: TOMAS ÄRLEMO

years seen a decrease in the total capacity in new connection cases linked to wind power. Instead, applications for the connection of major consumption have become a relatively new phenomenon. Svenska kraftnät has currently received applications for new connections of mainly wind power in the order of 18,000 MW for the period up to 2025. According to Svenska kraftnät's forecast for the future expansion of wind power, it is estimated that around 15 percent of this capacity will be built. A capacity of 18,000 MW is twice the installed capacity in all Swedish nuclear power plants and corresponds to 75 percent of the country's maximum power needs. In addition to this, there are all the applications made to the country's regional grid owners for connecting wind power at lower voltage levels. Corresponding requests for new connections of large electricity consumption or generally increased power demand are currently in the order of 4,000 MW.

Even if Svenska kraftnät in the past two years has seen a levelling off of the total capacity in applications related to wind power, the expanded certificate system will lead to a continued expansion in wind power, with an increase of 18 TWh by 2030. This corresponds to 6,000 MW of installed wind power if an availability of 3,000 full load hours per year is assumed for the new wind power. The extensive wind power development creates a significant challenge for Svenska kraftnät when planning the development of the grid. There is often considerable uncertainty about whether planned wind power investments will be made, the timing of their commissioning, and how extensive they will ultimately be. Many of the investigations done for prospective projects do not result in any connection due to the counterparty withdrawing at a late stage. These planning challenges are further emphasised by the permit processes for expanding the transmission grid normally being substantially longer than the equivalent processes for the granting of permits and construction of wind farms.

Offshore wind power currently constitutes a very small share of the planned wind power development and Svenska kraftnät has no on-going cases of directly con-nected offshore wind farms. The largest potential for large volumes of offshore wind power is in southern Sweden. Building offshore wind power is currently significantly more expensive than building onshore. This applies in particular to offshore wind farms located further out to sea that need to be connected to the transmission grid with HVDC connections. Svenska kraftnät's assessment is that, unless strong subsidies for offshore wind power are introduced, the main part of the planned wind power will be built onshore or at near-shore locations. The Energy Commission's report contains proposals on support for offshore wind power; however, it is unclear how extensive the support is intended to be. Connecting an offshore wind farm normally requires both a connection line from the wind farm to the closest connection point on land as well as extensive grid reinforcements to be able to transfer the power to the consumption areas. Normally, the benefit of the internal grid reinforcements goes only to the connecting wind farm, which shall thereby also pay for them through a so-called investment contribution. It is unclear if the proposals in the Energy Commission's report mean that only the connection line will be subsidised or if the internal grid reinforcements will also be subsidised. Given that there are good wind locations close near-shore and onshore, it can be strongly questioned whether such support can be socio-economically justified.

The connection of large single electricity consumers has again become relevant in recent years. Svenska kraftnät has received several applications that concern the connection of electricity-intensive industries, especially data centres. The large connection applications of up to 500 MW have to-date concerned sites in central and northern Sweden. Data centres and other electricity-intensive industry require high electric capacity and lead to a strongly increased power demand in the transmission grid where they are connected. The size of the demand makes it difficult to connect them without implementing grid reinforcements. This often means that the capacity of the power lines in the local area is not sufficient. It is mainly 220 kV power lines that feed the connection points that see the larger power demands.

In central Sweden, there is a need to renew several 220 kV power lines since they are approaching the end of their technical lifetime. When renewing these power lines, future transmission needs are taken into consideration. However, these reinforcements lie five to ten years into the future and in many cases, there will be a capacity shortage in the grid before the renewal is carried out. When entirely new connections are required to reinforce the grid, the lead time to establish a new line is also long. A lead time of five to ten years for a grid connection may appear too long for the participants who want to connect, perhaps data centres in particular, which can influence their final investment decision. As of yet, no agreements have been signed for connection of larger loads caused by data centres to the transmission grid.

Svenska kraftnät has also received several applications for connection of increased loads in metropolitan regions where there is an extensive capacity shortage in the electricity grid and the possibility of increasing the load is already limited at present.

Altogether, the considerable uncertainties for connections of both generation and demand represent a significant challenge for Svenska kraftnät when developing the grid. These challenges become all the more apparent when considering the long lead times for obtaining permits to build new power lines and the fact that Svenska kraftnät cannot build power lines on speculation.

8.2.2 Market integration

This category of grid investments aims to increase or maintain the trading capacity between the Swedish bidding zones and between Sweden and its neighbouring countries. Their purpose is to contribute to an integrated Nordic and European electricity market. The benefit of these projects is mainly due to them making it possible to use generation resources more efficiently and contributing to a greater security of supply by increasing the ability to transfer electricity from surplus to deficit areas.

Future needs for greater market integration are generally identified through analyses using various electricity market models. In the analyses, various scenarios and sensitivity analyses are used to identify the most robust and profitable reinforcement projects. The analyses are done partly within the scope of the European and Nordic planning work and partly in Svenska kraftnät's own work. Cooperation with the TSOs of neighbouring countries is crucial to be able to calculate socio-economic welfare and costs in the best way. Decisions on investments in new connections are made nationally and bilaterally when it comes to cross-border interconnections with other countries.

For this System Development Plan, Svenska kraftnät has not conducted a separate electricity market analysis to identify the need for new market integration projects. The needs identified are a combined view of the results from analyses done in other contexts.

Market integration during 2018-2027

The need for transfer capacity from north to south in Sweden is expected to in-crease in the next few decades. This is driven by the expansion of wind power in the north combined with the decommissioning of nuclear power and other thermal power in the south of Sweden. In addition to this is the increasing consumption in the south, which is driven in part by a greater number of people moving to metropolitan regions and in part by new electricity consumers in the form of, for example, data centres.

Svenska kraftnät's analyses show a need for greater transfer capacity, mainly over Cut 2 between bidding zones SE2 and SE3. Grid reinforcements are, however, only one of several measures that are needed to avoid large price differences between northern and southern Sweden and to ensure generation adequacy south of Cut 2. Greater demand response and energy storage can contribute to improving generation adequacy. In addition, new dispatchable generation will be needed south of Cut 2. None, however, of the latter measures are within Svenska kraftnät's areas of responsibility.

Besides increasing north-south flows in the grid, changed patterns are predicted in the trade balance with neighbouring countries. Strong connections with the neighbouring countries, which enable exports of electricity during periods of surplus and imports during deficits, are becoming increasingly important with the growth of intermittent electricity generation.

Svenska kraftnät has at present two grid investigations that concern market integration. One concerns the north-south capacity through Sweden and especially Cut 2 between bidding zones SE2 and SE3. The other concerns the replacement of the older HVDC connection Fenno-Skan 1 between Sweden and Finland. Two major market integration projects have begun and are in an early consultation phase; they are the third AC line between northern Sweden and Finland (SE1 – FI) and a new HVDC connection (Hansa PowerBridge) between Sweden and Germany (SE4 – DE).

In the longer term, the Nordic TSOs have agreed to investigate the need for greater capacity in a number of "corridors" where a potential need for more capacity has been identified between the Nordic countries. These corridors are described in the common grid development plan published by the Nordic TSOs in August 2017. The corridors that directly affect Sweden are the border between southern Sweden and southern Norway and between southern Sweden and Denmark. In addition to this, the need for more capacity between southern Norway and western Denmark and northernmost Norway and Finland will be investigated. The latter is mainly due to the extensive wind power development in these areas, which also affects the Swedish power system. In 2018 and 2019, Svenska kraftnät will together with the other Nordic TSOs investigate the long-term need for more capacity in these corridors and the consequences it has for internal reinforcement needs.

8.2.3 System reinforcements

System reinforcements are investments in the transmission grid made to strengthen or maintain operational reliability and thereby the long-term security of supply in the power system, even if the investments cannot be related to any specific connection or market need. The need for these investments arises as a result of on-going changes in, for example, the generation mix, load patterns, stability and power flows.

System reinforcements during 2018-2027

Within individual regions, there is an on-going increase in the total generation capacity. Likewise, consumption is increasing regionally in the metropolitan areas. Several of the system reinforcements planned during this period are being carried out to deal with the exchange of large power flows between regional generation and consumption centres across the transmission grid.

The transmission grid contains stretches with parallel 400 kV and 220 kV connections. The flow distribution between connections that is driven in parallel with different system voltages is in some cases unfavourable, which affects the grid's total transfer capacity. Grid reinforcements are therefore done to handle such limitations. In addition, a number of stability improvement measures are also being done to ensure the system's overall ability to dynamically maintain the voltage and transfer capacity.

The power supply to metropolitan areas is a challenge for Svenska kraftnät. Cities are growing as new housing is built and new infrastructure and new public services are established. This organic growth has been difficult for local and regional grid owners to forecast. Today, Svenska kraftnät sees difficulties in meeting larger demands in the major cities of Stockholm, Gothenburg, Malmö and Uppsala without extensive grid reinforcements.

A part of the challenge is that there is currently a lack of coordination of the overall objectives for the metropolitan regions. Today, for example, a municipality can invest extensively in the establishment of data centres that require more power from the transmission grid at the same time as the neighbouring municipality or even another part of the same municipality says no to the power line needed to enable the venture. Since the transmission grid's substations feed large areas, the municipalities' needs can also compete with one another. A municipality can have problems obtaining sufficient capacity for its organic growth if the neighbouring municipality gets there first and establishes data centres that use all the available capacity. The situation is made worse if the municipalities also strive to close local electricity generation since the generation needs to be replaced by additional power from the transmission grid.

To address the challenges with limited capacity for the big cities, both in the short and long term, a comprehensive view and collaboration are needed to find the best solution for society overall. It is important that municipal planning considers the limitations of the capacity in the electricity grid and the long lead time for grid reinforcements.

8.2.4 Reinvestments

Svenska kraftnät is responsible for meeting society's needs for a robust transmission grid by maintaining its technical function whilst retaining high personnel safety, high availability and low environmental impact. Svenska kraftnät also strives to do this in a cost-effective manner through regular maintenance and renewal of entire facilities.

A fault in the national grid can have major consequences for personnel safety, underlying grids, customers connected to the grids and, ultimately, electricity consumers. This means that Svenska kraftnät must plan and implement necessary reinvestment measures in dialogue with the transmission grid customers before the risk of faults occurring becomes too great.

When there is a risk that maintenance measures, or replacements of single components in the facility, are no longer enough for a facility to maintain its function, a total renewal of the facility is done.

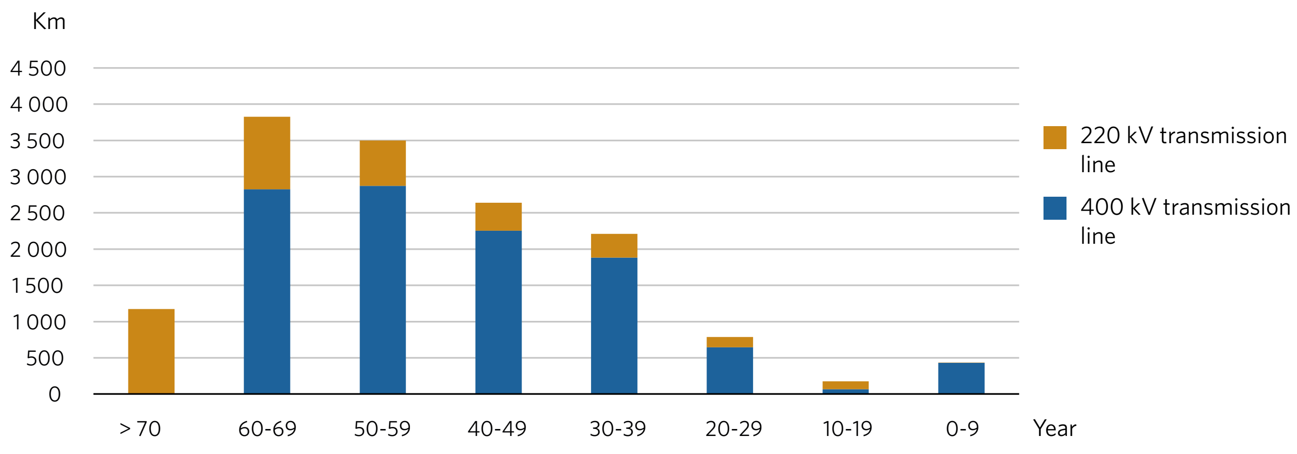


Figure 15: Age distribution of 400 and 220 kV power lines in the transmission grid.

Reinvestments during 2018-2027

Svenska kraftnät has long-term reinvestment plans within the upcoming ten-year period that comprise both grid substations and transmission lines. In 2018, the oldest parts of the transmission grid's 400 kV power lines will approach an age of 70 years and parts of the 220 kV grid are even older. These power lines have become so old that it is no longer enough to maintain them, rather they need to be renewed entirely. In total, this involves in all around 800 km based purely on renewal needs, but further measures may be added for other reasons.

In addition to these line renewals, Svenska kraftnät will also renew around 30 substations, 15 control facilities and ten reactors and transformers. In addition, a replacement programme is planned for a large number of individual devices and control system components where the individual costs are relatively small, but the total volume is significant. In the next ten years, it is estimated that between 40 and 50 units will be replaced every year, distributed over a varying number of substations. This means that nearly 500 high-voltage devices shall be replaced over the entire period.

Strategic management

The aim of facility management is for the facilities of Svenska kraftnät to have and maintain a high level of reliability with few faults and few outages, both planned and unplanned. The facilities shall also be safe for people, have a low environmental impact and the management shall be done cost-effectively.

Svenska kraftnät works proactively and continuously with facility management. Data such as error statistics and operating data is going to be used to a greater extent than today to be able to plan measures with greater accuracy. This strategy means that data on technical status forms the basis of reinvestment and maintenance plans. Reinvestments are necessary to maintain a low risk of functions in the facilities failing.

Outage planning is a major challenge if the reinvestment plans are to be implemented with a maintained operational security in the grid and with a limited negative impact on the electricity market. The outage possibilities that are available will primarily be used for larger measures. In terms of the smaller measures, in both substations and power lines, Svenska kraftnät sees advantages in doing a larger share of the work using live-line working methods in order to be able to maintain both operational security and trading capacity.

The impact of the need for reinvestment on grid development

Large parts of the 220 kV grid were built in the 1940s and 1950s for the needs that were then foreseen. The line grid was developed in the northern part of the country to connect and gather hydro power along the rivers. Further south, the 220 kV grid is designed to deliver electricity to industries and cities. Over the years, certain measures have been implemented on the power lines to be able to install more generation, but the available capacity is largely limited. In some parts of the 220 kV grid there is today a need both to install more generation in the form of wind power and to increase demand at certain connection points. To be able to accommodate this, extensive measures must be implemented.

When older power lines need to be replaced, consideration must be taken to the future transmission needs so that the capacity of the new power lines will be ade-quate. Today, Svenska kraftnät has standardised the technical design which often means a capacity increase when the line is reinvested in. The power lines built today are normally dimensioned for a higher transfer capacity. In some cases, this capacity increase of the 220 kV power lines may be sufficient, but in other parts of the grid, major changes are occurring that must be taken into account in the planning and here other aspects must be considered. An alternative is to increase the voltage in parts of the 220 kV grid to 400 kV, which provides significant capacity increases. One of the options being considered to achieve this is to build power lines with a 400 kV standard, but operate them with 220 kV until it is appropriate to increase the voltage. Here, costs, land access and future needs must be evaluated and compared for each of the options. Other options that can relieve some of the pressure from the 220 kV grid can be to build new transformer points such as is now being done in Hjälta.

8.3 Permits and technology choices

The requirements for greater operational security, together with energy and climate policy ambitions, are driving forces for Svenska kraftnät's grid investments. It is a question of building new facilities as well as maintaining and investing in the existing ones.

The changed transmission need and the large number of power line renewals that must be done to maintain operational and personnel safety in the transmission grid mean that the possibility to obtain permits for the necessary investments and reinvestments is of major significance to Svenska kraftnät's operations. It is thereby also of major importance for being able to fulfil the task that the Swedish Parliament and Government have given to Svenska kraftnät. The permit processes are crucial to how quickly the investments in the grids can be made.

8.3.1 Long lead times for permits

A series of permits from various authorities are required to build and operate facilities for electricity transmission. The requirement for high standards in the public consultations, choice of technology and environmental impact assessments mean that the permit process is extensive in terms of both time and effort. This is especially true of the long process to obtain a concession. Lead times of ten years from the investment decision to commissioning are not uncommon when it comes to new transmission lines.

8.3.2 Conflicting legislation

An ambiguous relationship between the Electricity Act and the Environmental Code may create barriers for Svenska kraftnät to carry out the tasks in the field of climate and energy policy as directed by Government and Parliament. In order for Svenska kraftnät to be able to carry out its mission, the conflicts between these laws must be resolved. Therefore, both Svenska kraftnät and the Energy Markets Inspectorate have brought up the need for a harmonisation.

For example, a ruling by the Superior Land and Environmental Court in reference to the Environmental Code, meant that Svenska kraftnät, at significant expense, was forced to move a line where they have had a concession under the Electricity Act for more than 40 years. This is despite a complete environmental review being carried out in every concession application under the rules of the Environmental Code.

8.3.3 Conflicts of interest and easement

Power lines and substations in the transmission grid involve conflicts of interest, environmental impact and land encroachment. The starting point for Svenska kraftnät when planning new power lines and substations is for the combined impact on people and the environment to be as small as possible. The impact on the surroundings and the conflicts of interest will be, however, impossible to avoid entirely.

For municipalities, land owners and any others affected, overhead power lines entail an extensive encroachment. The compensation levels under the rules of the Expropriation Act are also perceived to be too low. In addition to this, there is naturally the wish to not have large-scale infrastructure close to one's home or local environment.

Moreover, competition is increasing regarding the use of land. For example, it can be noted that other infrastructure, protection against the exploitation of nature and environmental interests, and the restriction zones of the Swedish Armed Forces can conflict with Svenska kraftnät's expansion plans.

Densely developed areas, such as cities, involve particularly complicated circumstances from an access perspective.

Svenska kraftnät aims to create dialogue and use information to create understanding for its mission and the need for a safe and operationally reliable electricity supply in Sweden.

8.3.4 Choice of transmission technology

The Swedish transmission grid is based on AC technology, which is the dominant technology at every level of the electricity supply. When Svenska kraftnät strengthens the transmission grid, it is generally done with overhead power lines. The selection of technology often leads to challenges with the permit process. The general public and other stakeholders would like power lines to be built as underground power cables to minimise the impact on the landscape and reduce the proportion of land used. An underground cable cannot, however, meet the requirements of Svenska kraftnät's mission regarding cost efficiency, operational reliability and environmental impact requirements in the same way as an overhead line.

An underground cable is eight to twelve times more expensive to build than an overhead line and has also only half the technical life expectancy. It is, however, the limitations concerning the technology and operational reliability rather than the financial aspects that lead to Svenska kraftnät avoiding underground cables in the AC grid.

Underground cables have different technical characteristics than overhead lines, which require reactive power compensation equipment to be installed every 20-40 kilometres on 400 kV connections. Each such compensation facility requires an area of around 120 by 60 metres, depending on the compensation need. In addition to the increased land use and the visual impact that the facilities entail, they also still have an untried technology combined with a high level of technical complexity and uncertainty.

In addition to the technical limitations for transfer capacity and compensation requirements, underground cables also affect the operational reliability of the transmission grid. Underground cables must be joined around every 700 metres and each joint, as well as each compensation facility, that is installed becomes a new potential source of failure in the transmission grid.

PHOTO: TOMAS ÄRLEMO

PHOTO: TOMAS ÅRLEMO

Another important factor for operational reliability is the repair time when faults occur. Underground cables take longer to troubleshoot and repair than overhead lines. The cables break more often than overhead power lines and this together with the longer repair time makes them a significantly worse alternative from the perspective of operational reliability.

In cities, where accessibility aspects make reinforcements with overhead power lines impossible, underground cables can be the only remaining option for a reinforcement of the grid. Also in these cases, underground cables should be used for as few and short sections as possible. The more underground cables, the greater the risk of electric resonance phenomena. In brief, the problems mean that the electrical properties of underground cables are such that they can contribute to harmful voltage increases in the electricity grid, resulting in potential operating interruptions. The resonance problem is more challenging for higher than lower voltage levels. This is expressed in concrete terms by the number of kilometres of underground cables that can be installed before a substantial risk arises as being less for high system voltages than for low voltages.

In addition, the different transmission characteristics of underground cables and overhead lines mean that they are not directly interchangeable with one another. An underground cable connection that was previously an overhead line can have a major impact on the transfer capacity from one area to another. A distorted distribution of energy flows on parallel power lines generally always arises. The typical case is that the underground cable is at risk of being exposed to excessively high currents in relation to the parallel overhead power lines that already exist. This can in turn create a need for even more new overhead power lines to create balance between the energy flows. Svenska kraftnät tries to avoid this type of scenario and naturally strives to not build more power lines than are necessary.

In practice, the phenomena with reactive power, resonances and the need for peripheral equipment mean that underground cable technology in the transmission grid is only a technically feasible alternative under special circumstances and for short distances.

8.4 Outages and impact on operation

Svenska kraftnät's extensive investment plans for renewing and reinforcing the transmission grid also increasingly affect the operation of the grid and trading capacity in the electricity market.

The implementation of the planned grid measures will lead to a greater need for interruptions in power lines and substations. If all of the needed interruptions can be spread out over a longer period of time, then no major problems will arise. However, in a situation with an ageing transmission grid, a high pressure to quickly connect new generation, a growing consumption in the major cities and a need for more integration with Europe, this option does not exist. It is therefore necessary to implement the investments rapidly so that security of supply does not decrease in the long term and so that the transmission grid does not become a limiting factor in the development towards a more sustainable energy system in terms of the climate.

The high rate of investment and reinvestment may mean that combinations of outages that together provide significant reductions of transfer capacity must be accepted. In many situations, Svenska kraftnät will be faced with a conflict between maintaining capacity for the electricity market and at the same time maintaining the power system's security of supply. In this choice, the power system's reliability must carry more weight. Svenska kraftnät therefore expects that temporary decreases in the trading capacity, as a result of the increasing number of outages, will become more common in the future than they have been to date. In such situations, it is of the utmost importance that all interruptions are as short as possible and that some work, for example, may need to be done with a live voltage. The long-term public benefit of the measures will be very large, but the costs for implementing them will increase.

Svenska kraftnät will also not have the possibility to move planned outages with short notice to the same extent as before if the market situation changes. Even if the estimated market cost during the interruption increases, the long-term conse-quence of postponing interruptions is that the necessary measures cannot be done on time.

8.5 Major investments in the transmission grid during the years 2018-2027

In this chapter, the major investments in the transmission grid in the next ten-year period are presented. The investments are arranged geographically, from north to south. A more detailed list with individual projects is in the appendix "10-year network investment plan".

8.5.1 Capacity between Sweden and Finland

Recently, the prices in Finland have been far above the prices in the other Nordic countries. This is largely because the costs for older condensing power are so high that it is no longer profitable. Another cause is that new market mechanisms in Russia have entailed higher costs resulting in a decrease of the import that Finland has historically had. When the new nuclear power reactor in Olkiluoto is brought online, Fingrid will need to restrict the import from Sweden by around 300 MW. This limitation is because they must be able to deal with a loss of the largest generation facility.

In 2016, a study was done which analysed the capacity need between Sweden and Finland; both AC and HVDC connections were analysed. The socio-economic welfare analysis showed overall a large Nordic electricity market benefit for a reinforcement of the trading capacity between the countries. The highest socio-economic profitability resulted from a third AC line between northern Sweden and Finland (SE1 – FI). The socio-economic benefits are, however, not evenly distributed between the countries, which mean that the investment costs will be distributed in proportion to the benefit for the respective country. The line is planned between the 400 kV substations Messaure in Sweden and Keminmaa in Finland.

On 23 November 2016, Svenska kraftnät's board decided to begin the planning of the line. The pre-study is expected to be finished in early 2018. The line on the Swedish side will be built by Svenska kraftnät and on the Finnish side by Fingrid and commissioning is scheduled for 2025.

When the connection is built, the trading capacity between Sweden and Finland will increase by 800 MW. It also facilitates a more effective utilisation of the regulation resources and reserves between the countries. At the same time, the robustness in the synchronous connection between Sweden and Finland is increased, i.e. the risk that Finland is separated from the rest of the Nordic region during an outage on any of today's power lines between the countries will decrease.

PHOTO: TOMAS ÄRLEMO

The common Swedish-Finnish grid study also analysed various HVDC alternatives. The reason for this is that the oldest of the two existing HVDC connections, Fenno-Skan 1, is beginning to approach the end of its technical lifetime. In order to not decrease the transfer capacity between the countries, this connection will eventually need to be replaced with a new one.

One option is to replace Fenno-Skan 1 roughly along today's route. The advantage of this option is that it will continue to be possible to operate the connection together with the newer Fenno-Skan 2. This means that no new return cable needs to be laid to prevent the return current from causing damage. The disadvantage with today's positioning is, however, that very large flows are concentrated to a small area in the grid on both the Swedish and Finnish sides, especially when Olkiluoto 3 is brought online. The option means that further reinforcements in both Sweden and Finland are necessary to be able to fully utilise the connection.

A significantly better alternative is to instead replace Fenno-Skan 1 with a new connection further north, from bidding zone SE2, which has a large generation surplus. In addition to such a solution requiring less reinforcement measures, it would also relieve Cut 2 and have significant technical grid advantages on the Finnish side as well. Therefore, for technical system reasons, focus lies on replacing the existing Fenno-Skan 1 with a connection between bidding zone SE2 and Finland. The connection between SE2 and FI goes under the name Kvarken and is estimated to be complete by 2030.

8.5.2 Markbygden

In a 450-square kilometre area west of Piteå and Luleå, the largest wind farm in Sweden today is planned: Markbygden. The plan is to establish up to 1,100 wind turbines with a total capacity of up to 4,000 MW. The implementation is divided into three phases. To connect the first phase, a new 400 kV station, Råbäcken, has already been built. A second station, Trolltjärn, is under construction; the plan is to connect the wind farm's second phase to this. The third phase, which comprises around 1,500 MW, is under investigation and the measures to connect it are still unclear, but to be able to manage such a large power, the transmission grid must likely be reinforced with new power lines.

8.5.3 The area around Midskog and Midskog-Järpströmmen

In the area around Midskog, there are currently several applications to connect new wind power generation, as well as to increase demand. In order to be able to handle all operational situations that can arise whilst maintaining operational reliability, the Midskog substation must be reinforced with a new transformer between 400 kV and 220 kV, and part of the existing 220 kV grid must be reinforced. The substation Midskog also needs to be renewed and a project is under way to replace it with a new substation just south of the current one.

Between the stations Midskog and Järpströmmen, two power lines are currently running in parallel, one 400 kV line and one 220 kV line. The 220 kV line is approaching the end of its technical lifetime and a total renewal of the line is required. The area is also in need of capacity increases as there are plans for new wind power and possibly an increased transfer capacity between Sweden and Norway. An investigation is under way to study the need for a capacity increase and how the existing 220 kV line can be replaced. The focus today is to replace part of the 220 kV grid with a new 400 kV line from Järpströmmen to the area around Midskog.

8.5.4 Capacity increasing measures in Norrland

The transmission grid in northern Sweden is characterised by long 400 kV power lines built with the aim of transferring electricity generated by hydro power in the north to the consumption located in the south of the country. A 220 kV grid also extends around the rivers in the north that historically served as a grid that connected the rivers' hydro power generation. In recent years, wind power generation has begun to be connected in parts of the 220 kV grid at the same time that applications have been received to connect larger consumption, such as data centres. This has in turn increased the need for transfer capacity at several places in the grid. The applications that Svenska kraftnät has received to connect new wind power are concentrated in the bidding zones SE1 and SE2 as a result of the good wind conditions and the low population density.

A specific study of the grid in northern Sweden has therefore been done to identify the measures necessary to be able to connect large amounts of wind power generation. The study has also looked at which measures are needed to ensure that the north-south transfer capacity is not reduced due to the limitations in the transmission grid within bidding zones SE1 and SE2. The goal has been to find the grid reinforcements that will be required regardless of how the wind power development is distributed in Norrland. The study's preliminary conclusion is that there is a reinforcement need in the form of capacity increases of one existing line and a need for another new 400 kV line to be able to meet the planned wind power expansion. The investigation is not yet entirely complete in identifying exactly how the final grid solution will look.

8.5.5 NordSyd

Cut 2, the transmission grid between bidding zones SE2 and SE3, forms the large dividing line between northern Sweden's large generation surplus and the southern parts of the country where a lot of electricity is consumed. Cut 2 consists of eight 400 kV power lines and three 220 kV power lines. The 220 kV power lines are the oldest and were built in the 1940s while the 400 kV power lines were built over longer period between 1952 up to the end of the 1980s. To increase transfer capacity, the 400 kV power lines are equipped with series compensation substations.

The oldest 220 kV power lines, and also the series compensation facilities, need to be renewed within the next ten-year period. The first renewals of the 400 kV power lines need to be completed around 2035, if only their technical life expectancy is considered.

PHOTO: JAN HALVARSSON

The forces that are driving grid development clearly affect the transmission need across Cut 2. With an expansion of wind power in the north, closure of nuclear power and increasing consumption in the south, the transmission across Cut 2 is expected to strongly increase. Limitations in the capacity in Cut 2 will have a large detrimental impact on the electricity market, as well as on the security of supply in southern Sweden. There are thereby clear motives to investigate a reinforcement of the capacity in connection with the planning of renewal measures.

Two main options are currently being investigated. One is based on the possibility of keeping today's fundamental grid structure and renewing, as well as reinforcing, power lines and other facilities in it, such as by replacing the 220 kV grid with 400 kV. The other option is to establish new power line sections. The design and placement of the series compensation substations would also be revised since they affect the possibility of connecting new generation to the power lines. The investigation is also considering possibilities and consequences of building double power lines (where two power lines are placed on shared poles). If any line is renewed as a double line before its required renewal, this could also simplify planned-outage management in a later phase of the renewal work.

The possibilities for planned outages are an important parameter in this work. If the capacity through Cut 2 is reduced during a long period of time due to a line being taken out of operation for renewal, it has a major impact on the electricity market and security of supply. Different options where the renewed line is completed before the old line is demolished are therefore being investigated.

By upgrading existing facilities and implementing supplementary measures, future capacity needs in Cut 2 can be satisfied. Some measures are already decided on and are being implemented. This includes shunt compensation in the new substations Karlslund and Grönviken to increase the limit of voltage collapse. Further shunt compensation is planned alongside the renewal of the Bäsna substation.

Other measures that are linked to the capacity in Cut 2 concern the 220 kV grid further south. The two eastern 220 kV sections between Krångede–Västerås–Enköping and Stadsforsen–Uppsala need a larger transfer capacity. For those, it may be relevant to upgrade the power lines to 400 kV, either as single or double lines. The objective of the line measures is to relieve the power lines from the north to the Stockholm region, especially Stackbo–Hamra and Untra–Valbo, which are heavily loaded in certain operating situations.

8.5.6 Uppsala

In southern Uppland, there are a number of 220 kV power lines that feed Uppsala and Roslagen. The area is facing considerable changes since the consumption in the Uppsala region is increasing steadily and extensive changes are planned in the regional grid. The area is also affected by changes occurring in the grid structure towards Stockholm and the reinvestment needs that exist in the current line grid.

Svenska kraftnät has begun work to prepare an overall and coordinated investment strategy for the area with the aim of identifying the best solution. The necessity to establish new power lines and stations for new transformers to the regional grid cannot be ruled out.

8.5.7 Stockholms Ström and Storstockholm Väst

Up to 2027, Svenska kraftnät will invest nearly SEK 6 billion (EUR 0.6 billion) in grid measures linked to reinforcing the supply to the Stockholm region. The measures are grouped together under the name Stockholms Ström. The programme comprises some 50 sub-projects and involves the distribution system operators of Vattenfall Eldistribution and Ellevio as well as Svenska kraftnät. It involves 21 municipalities in Stockholm County.

The background to the grid renewal in Stockholms Ström is a Government decision from 2004. In this decision, the Government tasked Svenska kraftnät to prepare proposals on the design of the future electricity grid in the Stockholm region. Together with the regional grid owners, Svenska kraftnät prepared a proposal on a new grid structure that would fulfil future requirements on availability, operational reliability and have a minimal impact on the environment. The proposal was presented in an interim report in 2005 and a final report in 2008.

The new grid structure means that part of today's relatively fine-meshed 220 kV grid will be phased out. In other parts of the grid, the voltage level is being raised from 220 kV to 400 kV. A new, partially underground 400 kV line is being established between Upplands Väsby in the north and Haninge in the south. The middle section of the new connection is built below the inner city in a drilled tunnel.

Together with the implementation of Stockholms Ström, around 150 km of over-head power lines will be removed. Municipalities and other land owners are co-financing Stockholms Ström in proportion to the value of the land that is thereby freed up for other use.

The large-scale use of 400 kV cable technology in the Stockholm area will need to many large technical challenges, mainly in terms of operation, electricity quality and voltage control. The cables' reactive power supply will largely be compensated by shunt reactors. In some substations, however, dynamic regulating resources are being considered in order to be able to regulate the voltage during different consumption situations.

The need for electricity has grown faster than was foreseen when the new grid structure for the Stockholm area was prepared in the 2000s. The population growth, reduced local electricity generation, new electricity-dependent infrastructure and a desire to establish the Greater Stockholm region as an international centre for data centres are the main reasons for the increased need.

To meet the sharply increased demand for electricity and ensure operational reliability in Stockholm County in the long term, Svenska kraftnät is planning further reinforcements in the form of a new north-south 400 kV connection, called Storstockholm Väst, through the western part of the region. It is intended to replace today's 220 kV connections on the section Hamra–Överby–Beckomberga–Bredäng–Botkyrka–Kolbotten. The measures include an upgrade of the 220 kV line between Odensala and Överby to 400 kV and a number of new transformer stations. The investment is estimated to roughly be in the order of SEK 4 billion (EUR 0.4 billion), in addition to the costs linked to measures in Stockholms Ström. The connection will be built in stages between the years 2023-2030.

8.5.8 Skogsäter–Stenkullen

Svenska kraftnät has an on-going project to build a new 400 kV line along the west coast between the substations Skogssäter and Stenkullen. Although the previous plans for a large wind power expansion in Västergötland, Bohuslän and Dalsland have been scaled down, the line is still very important. There are currently only two north-south 400 kV power lines north of

PHOTO: TOMAS ÅRLEMO

Gothenburg, which limits the transfer capacity and reliability of the electricity supply to the region.

When faults occur in the transmission grid, the parallel regional grid is at risk of being overloaded, resulting in extensive electricity outages. The new line between Stenkullen and Skogssäter prevents this and at the same time removes the current limitation in the transfer capacity across the west coast, which affects how much power can be exported to Norway (SE3-NO1).

The line's importance has increased markedly since Vattenfall decided to close two nuclear power reactors in Ringhals. This reduces the generation capacity in the western part of the bidding zone SE3 by nearly 1,800 MW. Since the generation loss must largely be compensated by generation outside of the area, such as by Swedish and Norwegian hydro power, the significance of a new north-south line will increase over time.

Nuclear power decommissioning also reduces the capacity for voltage regulation on the west coast, which in turn reduces the possibility of supplying power to the area from outside in an operationally reliable way. To compensate for the loss of the voltage regulation that Ringhals provides today, Svenska kraftnät is planning to replace today's automatic voltage regulation equipment at Stenkullen and install an additional four new shunt capacitors.

8.5.9 West coast power lines (SE3 and SE4)

Nine 400 kV power lines between Trollhättan and Malmö are now more than 60 years old and in great need of renovation. Foundations, poles and power lines have all corroded quickly due to the salt-laden winds. The work of replacing these power lines with a combined length of around 400 km will begin during the planning period, but will not reach completion during the period. This is due partly to the long permit processes, and partly due to limited possibilities for planned outages on these heavily loaded power lines.

8.5.10 Ekhyddan–Nybro–Hemsjö

Svenska kraftnät has applied for a concession for a new 400 kV line, approximately 200 km in length, from Ekhyddan in bidding zone SE3 through Nybro to Hemsjö in bidding zone SE4. After the cross-border interconnection NordBalt was connected to Nybro, the transfer capacity through the area has increased by 700 MW in both directions. The new line is needed to secure the operation of NordBalt and to improve the transmission grid's transfer capacity. It is also needed to increase operational reliability by ensuring that the parallel regional grid in Småland is not overloaded when faults occur in the 400 kV grid, resulting in extensive electricity outages. Until the line has been commissioned, a provisional system protection scheme has been installed that can disconnect NordBalt in the event of a critical fault in the transmission grid.

The line Ekhyddan–Nybro–Hemsjö also stabilises the generator O3 in the Oskarshamn nuclear power plant, so that it achieves the operational reliability that Svenska kraftnät requires from connected generation plants. This is especially important now when Uniper is closing the two oldest generators O1 and O2 in Oskarshamn. This means that O3 will take on an even more important role as the voltage stabilising generator in the area.

This line project has been deemed to be so important to the development of the common electricity market in Europe that the project has been assigned the status of a Project of Common Interest (PCI) by the European Commission.

8.5.11 Hansa PowerBridge

Svenska kraftnät's board decided in spring 2017 to continue with the next phase of the work in establishing a new HVDC connection between southern Sweden and Germany. This phase comprises work linked to seabed surveys, permits and land access as well as preparing the request documents for procurement. It is expected that a final investment decision will be able to be made at the end of 2022, which could result in the commissioning of the interconnection during 2025/2026.

Hansa PowerBridge is planned as an HVDC connection with 700 MW transfer capacity and is being developed in cooperation with the German grid operator 50Hertz. A cooperation agreement was signed at the beginning of 2017 to regulate the continued work.

The interconnection will connect to the transmission grid in Hurva outside Hörby in Skåne. This is the same substation that the HVDC connection SydVästlänken connects to from the north. This provides a possibility to transmit part of the power that comes from the SydVästlänken on to Germany without loading the surrounding AC grid.

The connection is of major importance to be able to integrate the large amounts of renewable electricity generation that will be built in Sweden and the Nordic region. The higher trading capacity between Sweden and Germany makes it possible to both export larger amounts of renewable energy in periods of surplus in the Nordic region, but also import when large surpluses in the rest of Europe provide lower prices there than in the Nordic region.

The increase in trading capacity is also of major significance to be able to import more power when the weather-dependent electricity generation in Sweden and the Nordic region do not generate sufficient electricity to cover consumption together with the other generation sources. This is something of particular importance since the closure of Swedish nuclear power is expected to lead to more occasions with a serious risk of power shortage in southern Sweden.

9. FINANCIAL DEVELOPMENT

SUMMARY

- The grid investments presented in the System Development Plan during the planning period for the years 2018-2027 entail a major economic undertaking. The combined investment volume amounts to SEK 60 billion (EUR 6 billion), of which SEK 45 billion (EUR 4.5 billion) are estimated during the planning period for the years 2018-2027. Of these, SEK 22 billion (EUR 2.2 billion) constitute reinvestments in existing substations and power lines and the remaining SEK 23 billion (EUR 2.3 billion) are for new investments.
- The financial development is dependent on several prerequisites and assumptions. Several projects are still in the planning phase, which is why there is uncertainty about when and in some cases if they will be implemented. Changes in the planned investment volumes have a significant impact on the financial development. Other factors that are difficult to assess and have a major impact on the financial development are interest and depreciation costs, as well as congestion revenues.
- According to the assumptions made, Svenska kraftnät's borrowing is estimated to amount to SEK 24 billion (EUR 2.4 billion) by 2027. This corresponds to a debt/equity ratio of 240 percent.
- The high investment rate is expected to lead to a doubling of the power charge component in the transmission grid tariff by 2027.

The transmission grid is in a period when the investment need is very extensive, which will have a major impact on Svenska kraftnät's financial development. The combined investment volume for the grid investments presented in the System Development Plan amounts to SEK 60 billion (EUR 6 billion), of which SEK 15 billion (EUR 1.5 billion) occur outside the planning period 2018-2027.

For the planning period 2018-2027, the investments amount to SEK 3 - 7 billion (EUR 0.3 – 0.7 billion) per year with a combined investment volume of SEK 45 billion (EUR 4.5 billion). Of this, investments in new power lines and substations comprise around SEK 23 billion (EUR 2.3 billion). Reinvestments in existing sub-stations and power lines are estimated at SEK 22 billion (EUR 2.2 billion).

The development of Svenska kraftnät's investments split between the four driving forces of connection, market integration, system reinforcement and reinvestment is presented by Figure 16. It should be noted that an investment can include more driving forces than its main driving force. The amounts in the figure are gross figures, i.e. investment grants from external parties are not included.

9.1 Financing

Svenska kraftnät's investments are financed partly through loans via the Swedish National Debt Office and partly through self-financing. In addition, there are another two significant financing sources: investment grants and congestion income.

Investment grants are the most common source of financing when new electricity generation or new electricity consumption comes into the system, such as data centres. In these cases, grid companies are obliged to connect both of these to the grid. If there is no available capacity in the grid or if the operational reliability is negatively impacted, the connecting producer or electricity consumer might pay an investment grant to finance the investment required so that they can connect. An investment grant can also be given by, for example, property owners when the grid expansion will lead to valuable land being released. A prerequisite for this is that it is possible in technical system terms without the operational reliability deteriorating and that a new acceptable piece of land can be found.

Congestion revenues are another important source of financing; these result from price differences between neighbouring bidding zones, either between countries or Swedish bidding zones. Congestion revenues that arise between Swedish bidding zones are allocated 100 percent to Svenska kraftnät. For congestion revenues that arise between countries, 50 percent[23] is allocated to Svenska kraftnät and 50 percent to the neighbouring country's TSO.

23. For SwePol Link, a pilot is under way that will lead to another distribution.

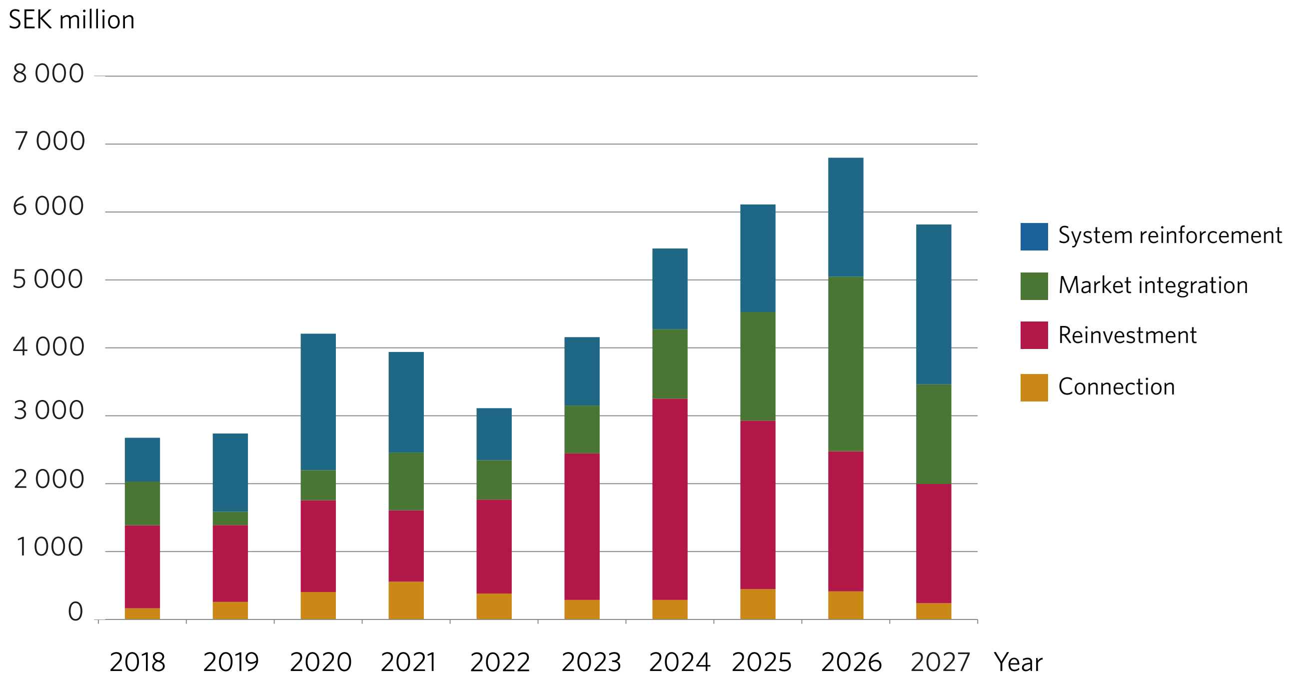


Figure 16. The investment levels in 2018-2027 distributed between the main drivers for the grid investments.

9.2 Conditions and challenges for financial planning

The planning of Svenska kraftnät's financial development requires several assumptions. The financial development is also strongly dependent on a number of factors that result from the investments, such as interest and depreciation costs, and which in many cases are hard to forecast accurately.[24]

Svenska kraftnät currently has a required rate of return from the Government of 6 percent on adjusted equity over an economic cycle. This is assumed to apply unchanged during the period. The Government has, however, begun a review of the required return. If the review leads to a changed required rate of return, it will probably have significant consequences for the financial development.

Besides the Government's required rate of return, Svenska kraftnät's revenue levels from grid operations are also regulated by the revenue limits set by the Energy Markets Inspectorate. Given the assumptions that this plan is based on and provided that the required rate of return that Svenska kraftnät is subject to is unchanged, the revenue limit provides sufficient space for Svenska kraftnät's revenue requirements. However, the revenue limit includes efficiency requirements on what the regulation calls controllable costs, such as costs for staff, operations and maintenance. The expansion of the transmission grid will lead to higher levels for all cost items, even if the authority increases cost efficiency. This is not taken into account in the revenue limit and hence, in a long-term perspective, the authority could find it difficult to stay within the levels that the regulation allows.

The financial planning and development is strongly dependent on the investment volume, which in itself involves extensive uncertainty. Investments that are in the implementation phase can be assumed to have an outcome close to that planned, while investments that are in the planning phase, and are therefore not yet approved, are less certain. Planned connections for wind power have, however, a tendency to be postponed or discontinued due to, for example, financing difficulties or a change in the profitability evaluation by the wind power developers. A number of wind power connections are included in the System Development Plan but there is extensive uncertainty about which will be implemented. Even less certain are investments categorised as under consideration. Here there is a risk that they are either discontinued or that volumes and timetables change. Figure 17 shows the quantity of the annual investment volume, split between each respective phase. The investment volume for the period 2018-2027 is calculated to amount to SEK 45 billion (EUR 4.5 billion). Of these investments, a large part is still not decided, which can give some indication of how much of the annual investment volume is associated with uncertainty.

The main cost increase that Svenska kraftnät's investments are estimated to give rise to are comprised of interest and depreciation costs, which are both difficult to forecast.

To forecast assumptions for both interest levels and inflation, Svenska kraftnät uses the National Economic Research Council's forecast as a basis. The assumed interest rate is -0.4 percent at the beginning of the planning period and 3.1 percent at the end. Given the high level of borrowing planned for Svenska kraftnät, any deviation from the assumed interest rate has a

24. It should also be noted that the financial development presented in this plan only takes into account the investments that are pursuant to the network development. This means that any measures that are due to system challenges as per above have not been taken into account in the financial estimates.

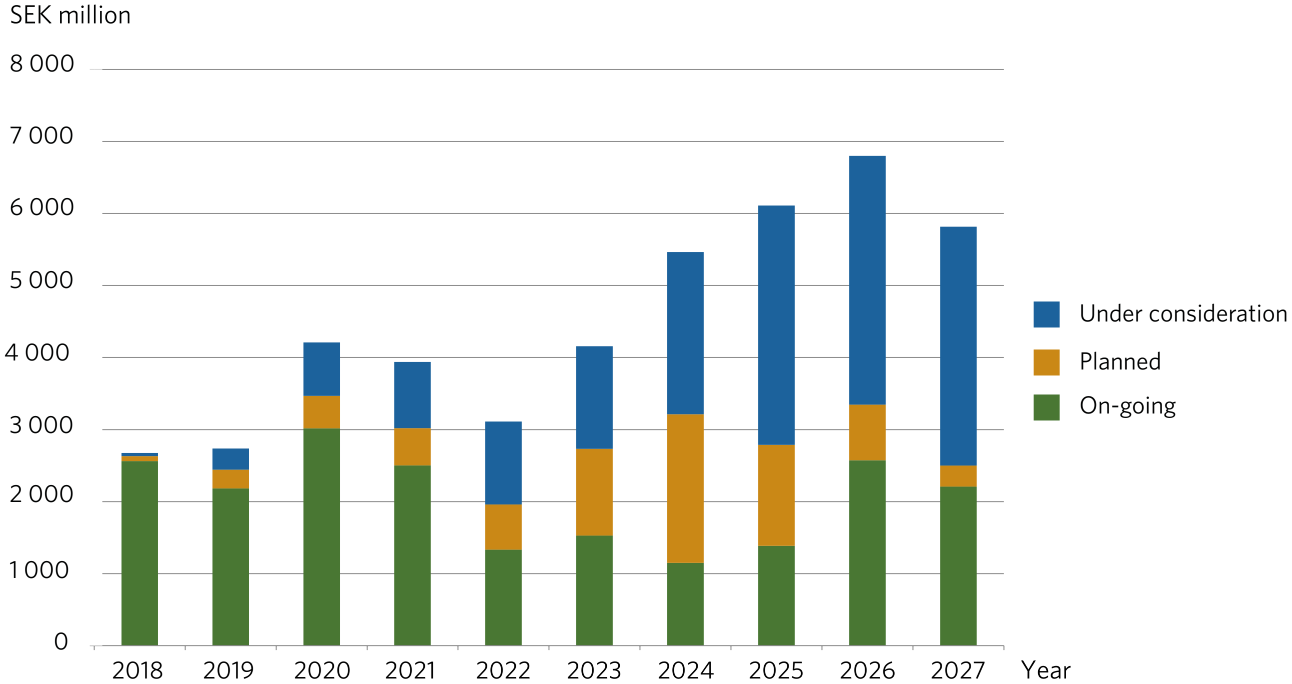


Figure 17. The annual levels for grid investments divided by project phase.

major impact on the financial development.

Svenska kraftnät's extensive investment need has a direct impact through higher depreciation costs, as well as an indirect impact through an increase in the costs for operations and maintenance. The planning of Svenska kraftnät's depreciation costs is dependent on the investment projects' commissioning date, which is difficult to forecast with accuracy. The projects' long lead times entail difficulties in estimating timetables and upcoming commissioning dates. In addition, timetables can be postponed for many different reasons and affect the projects' commissioning date, and consequently the planning of the depreciation costs. During the planning period, it is estimated that the depreciation costs will nearly double from SEK 1.1 billion (EUR 0.11 billion) at the beginning of the period to SEK 2.0 billion (EUR 0.2 billion) at the end of 2027.

The impact on costs when a number of projects and the corresponding depreciation costs and interest are no longer in the plan can be illustrated by an example. If planned projects of around SEK 1 billion (EUR 0.1 billion) with a depreciation period of 40 years and assumed interest rate of 3 percent are no longer in the plan, it will affect the tariff with a lower cost of around SEK 60 million (EUR 6 billion) per year, which corresponds to a lower tariff of 1 to 3 percent annually.

Another factor that has a large impact on the financial development is the receipt of congestion revenues. In recent years, the congestion revenues have been a significant source of financing for Svenska kraftnät, but they are very difficult to forecast. The total income from congestion revenues is determined by the differences in electricity prices that arise in electricity trade between countries and between Swedish bidding zones. The differences depend in turn on the conditions that the electricity market experiences such as weather, availability of water in water reservoirs, nuclear power availability, and transfer capacity between bidding zones and on cross-border interconnections. These factors are difficult to assess already one year in advance and even harder ten years in advance. Historically, since the bidding zones were introduced in Sweden, congestion revenues have varied between SEK 700 million (EUR

PHOTO: TOMAS ÅRLEMO

70 million) and SEK 2,100 million (EUR 210 million) annually. In this plan, the congestion revenues were calculated to between SEK 700-1,000 million (EUR 70-100 million) per year, of which an average of around 70 percent pertain to congestion revenues between countries.

9.3 Financial position

The investments in the System Development Plan for the planning period 2018-2027 will have significant consequences for Svenska kraftnät's finances and the transmission grid tariff charged to grid customers. With the aforementioned conditions and assumptions of input parameters, it is estimated that Svenska kraftnät's [25] borrowing for 2027 will amount to SEK 24 billion (EUR 2.4 billion). This corresponds to an increase of the debt/equity ratio of a full 150 percentage points to 240 percent at year-end 2027. The equity/assets ratio is deemed to drop from 29 percent at the period's beginning to 19 percent at the end of 2027.

The key financial performance indicators would for a private company indicate an unsound financial position and it would be difficult and costly for Svenska kraftnät to finance the investments if Svenska kraftnät were not a part of the State and able to borrow from the Swedish National Debt Office. The development of borrowing during the period 2018-2027 is presented in Figure 18 and the developments of the equity/assets ratio and the debt/equity ratio during the period 2018-2027 are presented in Figure 19.

Besides loans, the investments are financed by self-financing, grants and congestion income. The distribution between various sources of financing for the invest-ments during the period 2018–2027 is presented in Figure 20[26]. As shown by the figure, it is mainly borrowing that increases when the investment levels peak.

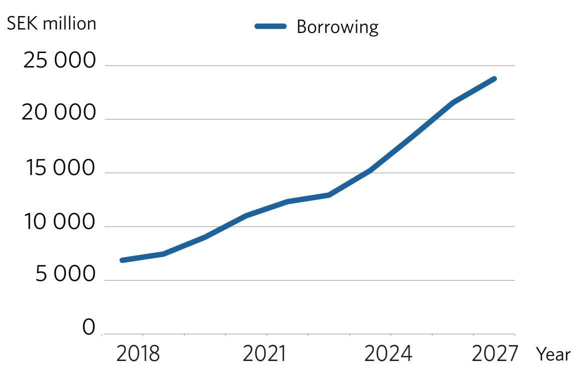


Figure 18. Forecast development of Svenska kraftnät's borrowing up to 2027.

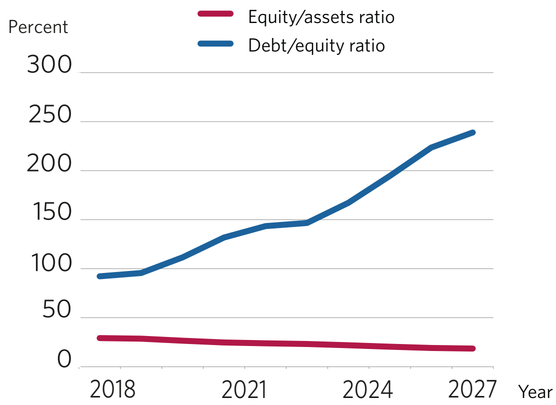


Figure 19. Forecast development of Svenska kraftnät's equity/assets ratio and debt/equity ratio up to 2027.

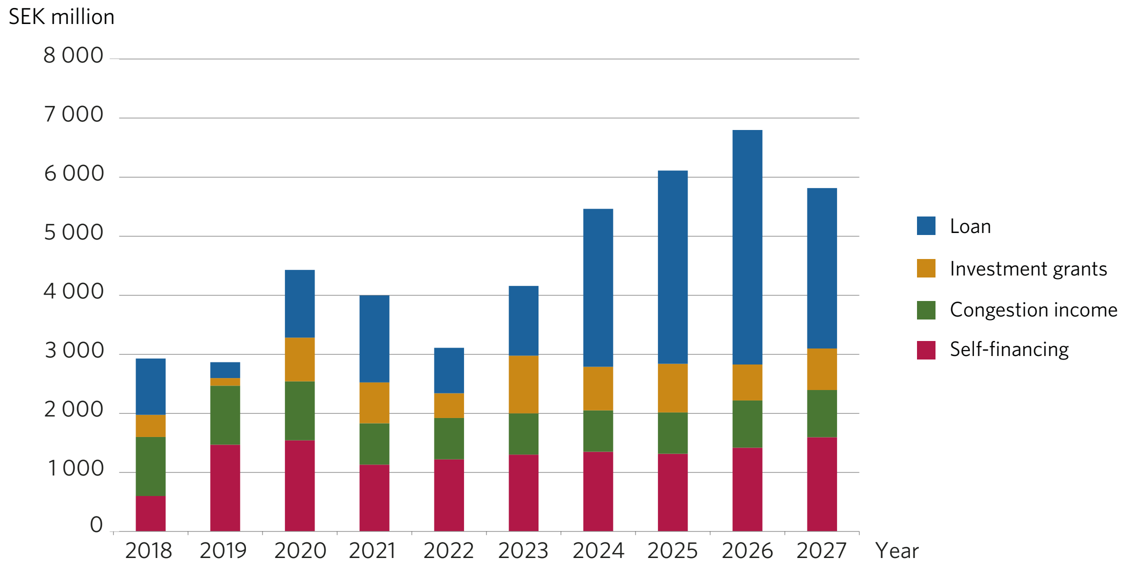


Figure 20. Distribution between different sources of financing for the investments until 2027.

25. The financial position is estimated based on the group Svenska kraftnät, i.e. Svenska Kraftnät Gasturbiner AB is included in the estimates.
26. In addition to network investments, IT investments are included in an amount of around SEK 700 million (EUR 70 million) in 2018–2021.

In light of the various sources of funding, it may be interesting to compare how well the investments divided by main driving forces follow the financing of them. An ideal distribution occurs if the investments with the driver of connections are to be financed with investment grants, market integration investments that aim to reduce bottlenecks and increase capacity between bidding zones are to be financed by congestion income, and investments that strengthen the transmission grid, system reinforcements, are to be financed by new borrowing. Reinvestments should be financed by self-financing, i.e. Svenska kraftnät should generate a profit that contributes to reinvestment in the existing facility portfolio. That said, a perfect and unambiguous distribution is not possible since every investment is categorised by a main driver whilst they can often be motivated by other drivers. A relatively even distribution should, however, be obtained. Figure 21 shows the relationship between the investments by main driver and their sources of financing during the planning period for 2018-2027. During the planning period, investments driven by market integration match their corresponding source of financing relatively well. Investments with the driver of connections are somewhat lower than investment grants which is explained by compensation from property owners also being included in the item of investment grants. For reinvestments, the self-financing is significantly lower than the investment level, which can indicate Svenska kraftnät's required rate of return needs to be raised or the dividends reduced. However, there is some uncertainty for the reinvestments since they can include some new investments.

9.3.1 Transmission grid tariff

The increased costs that the investments give rise to are paid mainly by Svenska kraftnät's grid customers through the transmission grid tariff. The grid customers pay through the transmission grid tariff for all generation input to and electricity withdrawn from the transmission grid and it is mainly the power charge[27] that should cover the higher costs.

Altogether, the high investment rate means that the power charge must be raised. Over the entire planning period 2018-2027, the increase is estimated to amount to a total of around 100 percent. It is important to note that the estimate applies generally to all users of the transmission grid. For the individual grid customer, the eventual outcome can differ to this number, depending on the fee structure and where in the grid the customer is connected.

Figure 22 illustrates the development of Svenska kraftnät's total revenues for the power charge.

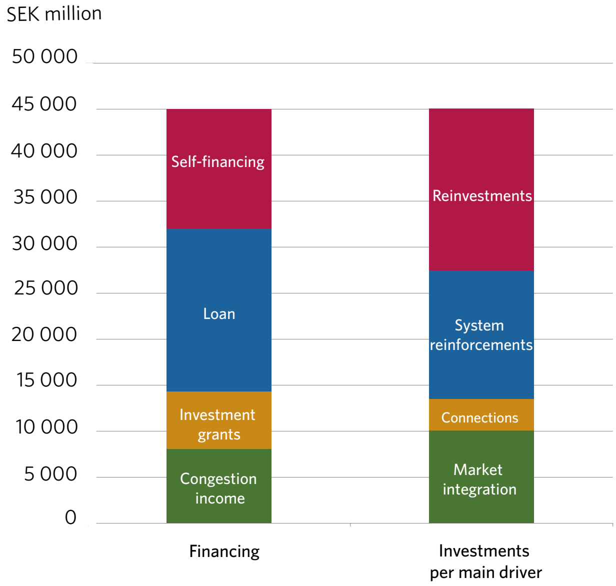


Figure 21. The relationship between the investments by main driver and their sources of financing during the planning period for 2018-2027.

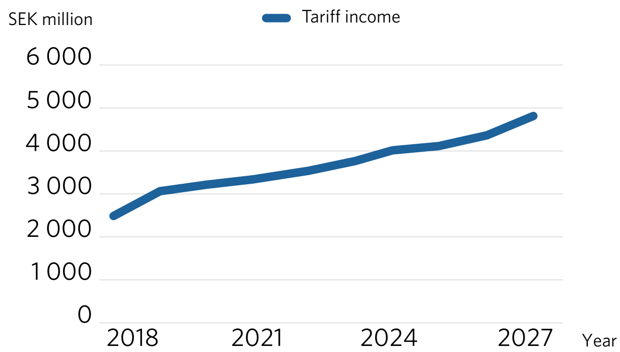


Figure 22. Development of the authority's tariff revenues from power charges until 2027.

27. The transmission grid tariff's second part (in addition to the power charge) is the energy charge. The energy charge shall cover the authority's costs for procuring the losses that the transmission on the transmission grid gives rise to. The development of the energy charge is accordingly largely dependent on the electricity price development and only indirectly on the network expansion through the increases or decreases of the losses this gives rise to.

PHOTO: TOMAS ÅRLEMO

APPENDIX.
10-YEAR NETWORK INVESTMENT PLAN

This appendix presents the investments in the transmission grid that are today deemed to happen during the ten-year period 2018-2027[1]. The projects presented in the plan comprise today's best assessment. New projects will gradually be added while others will be removed or be adjusted in time and scope. It is an unavoidable consequence of the many parameters that affect the conditions and driving forces for the investments. Development work is also constantly under way on fundamental assumptions for the investment plan in the form of e.g. planned outage possibilities and resource usage.

The appendix is mainly divided by bidding zones. Within each bidding zone, the projects are presented in tables and geographically in the form of maps[2].

Bidding zone SE1: includes Norrbottens and some of Västerbotten County. Major cities in the area are Kalix, Haparanda, Luleå, Piteå and Skellefteå.

Bidding zone SE2: includes Västernorrland and Jämtland counties, and parts of Västerbotten, Dalarna and Gävleborg counties. Major cities in the area are Umeå, Örnsköldsvik, Härnösand and Sundsvall.

Bidding zone SE3: includes most of central Sweden. This includes the counties of Stockholm, Uppsala, Västmanland, Örebro, Södermanland, Östergötland, Värmland, Gotland and Västra Götaland, and parts of Dalarna, Gävleborg, Halland, Jönköping, Kronoberg and Kalmar counties. SE3 has eight of Sweden's ten largest cities – Stockholm, Gothenburg, Uppsala, Västerås, Örebro, Linköping, Jönköping and Norrköping.

Bidding zone SE4: includes Skåne and Blekinge counties, and parts of Halland, Jönköping, Kronoberg and Kalmar counties. Major cities in the area are Malmö, Lund, Helsingborg, Ystad, Trelleborg, Karlskrona and Kalmar.

The projects in each area are in turn divided into three categories: on-going, planned and under consideration.

On-going projects

A project is classified as on-going when Svenska kraftnät has decided to start implementation. Svenska kraftnät also sees the work of obtaining necessary permits as a part of this. On-going projects can in exceptional cases not be realised, but adjustments of such projects normally involve changes in timetables or cost estimates, often as a result of reprioritisation, delay or improved information on costs.

Planned projects

A project is classed as planned when it is between investigation and decision on project start. Here, in-depth technical pre-studies are done that aim to provide a better basis for timetables and cost estimates. In projects with external parties, work is under way to establish potential agreements. There are planned projects that are not realised as intended. Often, this involves projects concerning connections of external parties. In these cases, Svenska kraftnät is not the only one in charge of the decision-making process. The implementation can, for example, be dependent on a wind power developer receiving funding for its project to be able to sign a connection agreement with Svenska kraftnät.

Projects under consideration

A project is classified as under consideration when an investigation is under way on the conditions for an investment to be implemented. This category also includes projects for which such an investigation has not yet begun, but where a clear need to take action in the next ten years has been identified. The majority of these concern reinvestments that need to be initiated within the ten-year period where the respective facility is approaching the end of its technical lifetime. Projects that concern connections of external parties are not included in the Appendix in those cases where the conditions have not yet been investigated. The category of under consideration has the greatest uncertainty as to if and when projects will be implemented.

Table explanations

The tables for each bidding zone and phase contain the following information:

No.: serial number shown on the map for the respective bidding zone.

Project start: estimated time for the beginning of the project.

Commissioning: planned time for bringing the facility into operation. If this occurs in stages, the date is the time for the first stage commissioning.

Cost: the total estimated cost including investments and expenses. The uncertainty in the estimate is greater in earlier project phases which is why the expense for them are given as ranges. Projects for which the cost is deemed to be less than SEK 5 million (EUR 0.5 million) are not included in the appendix.

Driving force: the projects' driving forces can be divided into Connection, Market Integration, System Reinforcement or Reinvestment. The driving forces are described in Chapter 8.2. The tables present the respective project's main driving force.

1. The investments in the subsidiary Svenska Kraftnät Gasturbiner AB is not included in the appendix.
2. Data source background maps © Lantmäteriet

B.1 Bidding zone Luleå (SE1)

ON-GOING PROJECTS SE1

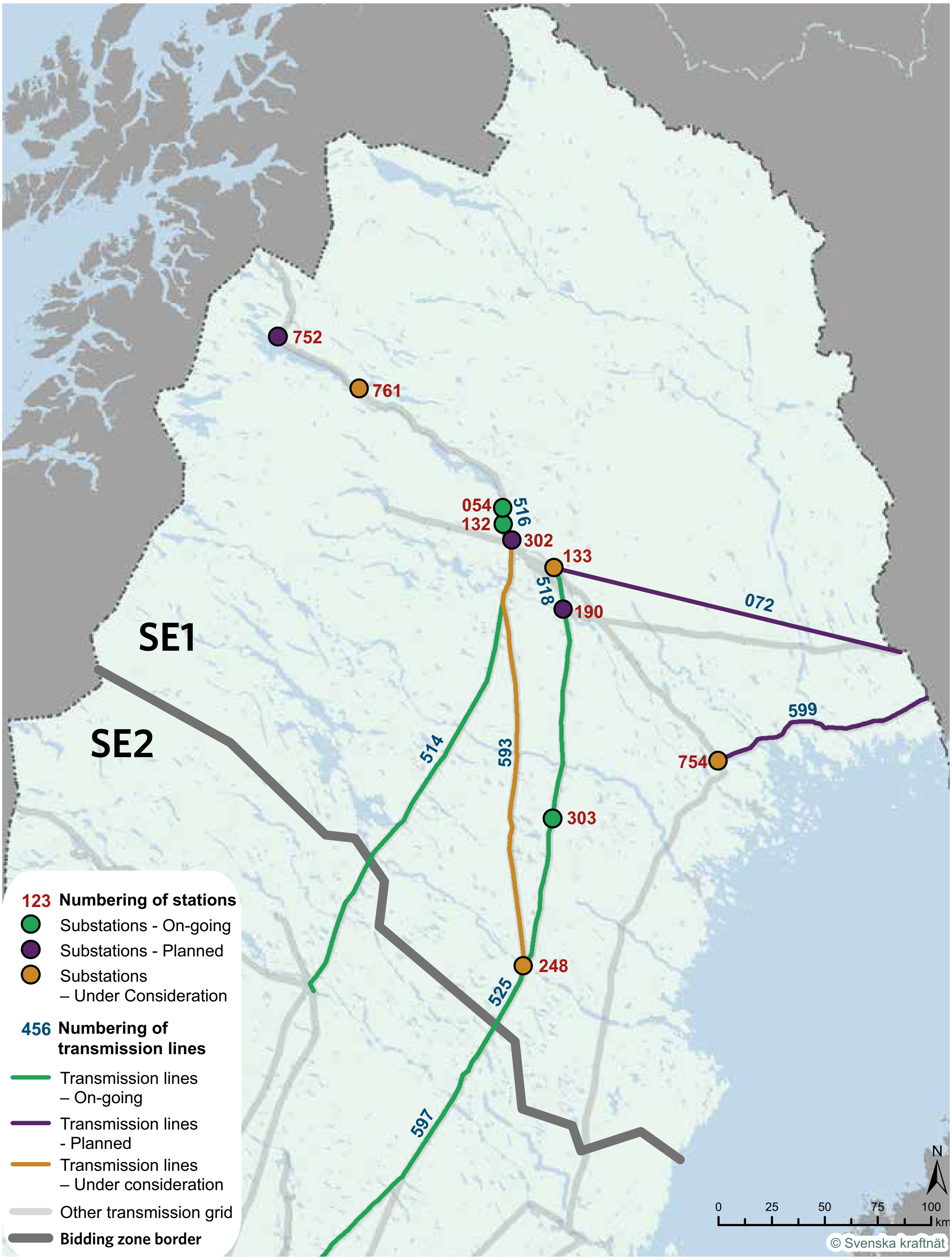
NO	PROJECT	COMMISSIONING	COST (MSEK)	DRIVING FORCE
303	Trolltjärn ny 400 kV-station anslutning UL6 S3-7	2020	120	Connection
054	Porjusberget stationsförnyelse Porjus PK1	2018	190	Reinvestment
597	Letsi - Betåsen UL6 S3-7 status åtg	2018	5	Reinvestment
516	Harsprånget-Porjus UL24 S1 opto	2018	5	Reinvestment
525	Vargfors-Tuggen UL7 S1 statusåtg	2019	35	Reinvestment
132	Harsprånget PK2 stationsförnyelse	2020	120	Reinvestment
518	Messaure-Letsi UL6 S2 opto	2020	5	Reinvestment
514	Porjus-Grundfors UL1 S1-3 opto och statusåtg	2020	50	Reinvestment

PLANNED PROJECTS SE1

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
072	Messaure-Keminmaa ny 400 kV-ledning	2018	2026	Approx. 2 billion SEK	Market Integration
599	Förv.proj Svartbyn - Finska gränsen UL21 status åtg	2018	2020	Over 5	Reinvestment
752	Ritsem PK51 stationsförnyelse	2017	2021	Over 25	Reinvestment
190	Letsi PK46 stationsförnyelse	2018	2022	Over 100	Reinvestment
302	Ligga PK3 stationsförnyelse	2018	2023	Over 100	Reinvestment

PROJECTS UNDER CONSIDERATION SE1

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
133	Messaure PK4 stationsförnyelse	2019	2024	Over 25	Reinvestment
761	Vietas PK52 stationsförnyelse	2020	2024	Over 25	Reinvestment
754	Svartbyn UT42 stationsförnyelse	2020	2025	Over 25	Reinvestment
248	Vargfors NK25 stationsförnyelse	2022	2027	Over 100	Reinvestment
593	Ligga-Vargfors UL25 statusåtg	2026	2028	Over 5	Reinvestment



Project overview SE1

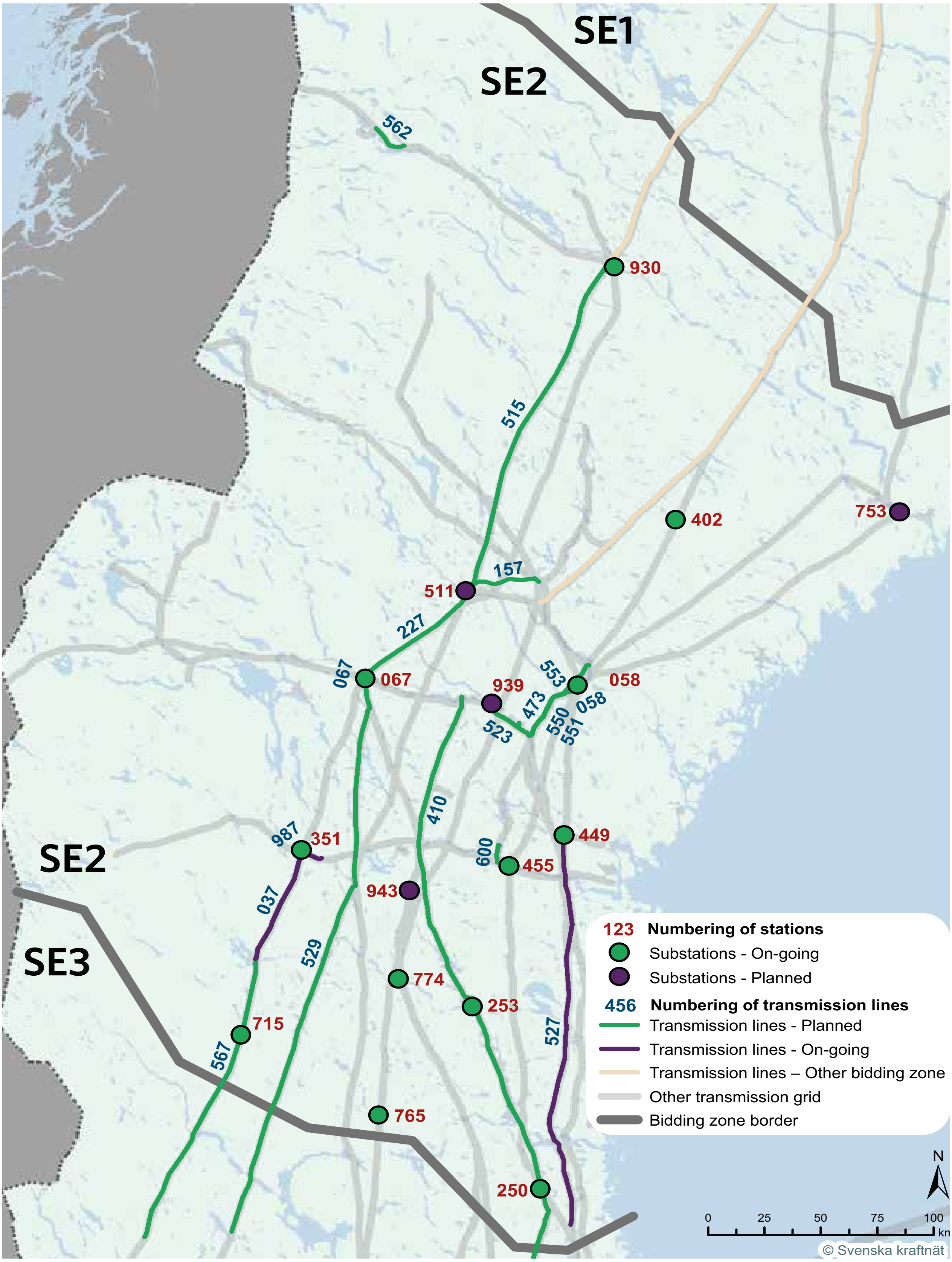
B.2 Bidding zone Sundsvall (SE2)

ON-GOING PROJECTS SE2

NO	PROJECT	COMMISSIONING	COST (MSEK)	DRIVING FORCE
449	Nysäter CT32 anslutning vindkraft	2018	20	Connection
058	Hjälta-området - ny 400/220 kV-transf - stationsåtgärder	2018	160	System Reinforcement
774	Laforsen RT72 anslutning vindkraft	2018	15	Connection
227	Storfinnforsen-Midskog ledningsförnyelse	2018	410	System Reinforcement
473	Hjälta-området ny 400/220 kV-transf - ledningsåtgärder	2018	100	System Reinforcement
250	Grönviken ny 400/130 kV-station, anslutning på UL17	2019	160	Connection
157	Långbjörn-Storfinnforsen ny 400 kV-ledning	2020	330	System Reinforcement
765	Gäddtjärn ny 400 kV-station ansl CL4 och förnyelse EK4 Djurmo	2021	230	Connection
402	Norrtjärn ny 400/130 kV-station anslutning UL7 S2	2021	80	Connection
715	Olingan ny 400 kV-station anslutning CL26 S3-4	2021	80	Connection
253	Ljusdal RT22 Utbyte haverad X1	2018	15	Reinvestment
523	Hammarforsen-avgr Svarthålsforsen RL3 S1-2 S9 statusåtg	2018	5	Reinvestment
410	Krångede-Horndal	2018	150	Reinvestment
562	Ajaure-avgr Gejmån AL7 S3 statusåtg	2018	5	Reinvestment
	Avveckling av frånskiljare 9 påstick i område Norr	2018	10	Reinvestment
553	Forsse avgr AL5 S8 statusåtg	2018	10	Reinvestment
551	Stadsforsen-Forsse AL5 S1, S2-3 statusåtg	2018	10	Reinvestment
550	Stadsforsen-Hjälta kraftstation AL4 statusåtg	2018	15	Reinvestment
067	Midskog IK2 stationsförnyelse och anslutning vindkraft	2019	490	Reinvestment
351	Rätan CT269 förnyelse flytt T3 och anslutning vindkraft	2019	280	Reinvestment
455	Stöde UT73 stationsförnyelse	2019	100	Reinvestment
529	Förv.proj Midskog-Kättbo CL1 S2-3 statusåtg	2019	10	Reinvestment
567	Rätan - Tandö CL26 S3-4 status åtg	2020	10	Reinvestment
930	Grundfors NK6 stationsförnyelse & anslutning vindkraft	2022	250	Reinvestment
600	Torpshammar-avgr Torpshammar RL22 S8 ledningsförnyelse	2022	40	Reinvestment
515	Grundfors-Storfinnforsen UL1 S4-5 opto och statusåtg	2022	35	Reinvestment

PLANNED PROJECTS (SE 2)

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
511	Storfinnforsen CT90 anslutning vindkraft	2017	2021	Over 5	Connection
943	Tovåsen ny 400 kV-station anslutning CL7 S1-2	2018	2022	Over 25	Connection
939	Hammarstrand ny station	2018	2022	Over 25	Connection
037	Rätan CT269 anslutning av RL22 S1 och RL5 S7	2018	2024	Over 25	System Reinforcement
527	Nysäter-Vittersjö CL3 S2 statusåtg	2018	2020	Over 5	Reinvestment
753	Stornorrfors NK1 stationsförnyelse	2019	2023	Over 100	Reinvestment
987	Rätan RT52 ny 220 kV ledning	2018	2023	Over 5	Reinvestment



Project overview SE2, on-going and planned

Project overview SE2, under consideration

PROJECTS UNDER CONSIDERATION, SE2

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
	Kapacitetshöjande apparatåtgärder i SE2	2018	2019	Over 5	System Reinforcement
403	Betåsen - Hjälta, ny 400 kV - ledning	2019	2027	Over 500	System Reinforcement
404	Kilforsen - Ramsele, kapacitetsuppgradering av ledning	2019	2027	Over 100	System Reinforcement
777	Midskog-Järpströmmen KL8 uppgr 400 kV	2019	2028	Over 500	System Reinforcement
946	Kvarken - ny HVDC SE2-FI	2020	2029	Approx. 3 billion SEK	Market Integration
	Snitt 2 förnyelse av 400 kV-ledning	2019	2030	Approx. 5.5 billion SEK	System Reinforcement
221	Bågede-Linnvasselv AL1 S3-6, S8, S9 opto	2019	2022	Over 100	Reinvestment
962	Stadsforsen IK1 stationsförnyelse	2019	2022	Over 100	Reinvestment
071	Kilforsen IK33 stationsförnyelse	2018	2023	Over 25	Reinvestment
760	Vaple RT571 stationsförnyelse	2019	2023	Over 25	Reinvestment
547	Förv.proj Degerforsen avgr-Gulsele AL3 S2, S9 statusåtg	2020	2023	Over 5	Reinvestment
546	Förv.proj Långbjörn-avgr Degerforsen AL3 S1 statusåtg	2020	2023	Over 5	Reinvestment
533	Bågede avgr-Linnvasselv AL1 S3-6, S8, S9 statusåtg	2019	2023	Over 5	Reinvestment
532	Förv.proj Långbjörn-Havsnäs-Bågede AL1 S1-2, S7 statusåtg	2019	2023	Over 5	Reinvestment
756	Söderala RT80 stationsförnyelse	2019	2024	Over 25	Reinvestment
090	Utbyte av reaktor X1 i KT82 Mörsil	2020	2024	Over 5	Reinvestment
749	Mörsil KT82 stationsförnyelse	2020	2025	Over 25	Reinvestment
531	Nysäter-Bandsjö CL3 S9 opto	2023	2025	Over 5	Reinvestment
522	Hällsjö-Vaple RL57 opto	2023	2025	Over 5	Reinvestment
744	Lasele IK34 stationsförnyelse	2021	2025	Over 25	Reinvestment
152	Ånge-Laforsen RL7 S2 ledningsförnyelse	2020	2025	Over 250	Reinvestment
729	Forsmo IK31 stationsförnyelse	2021	2026	Over 25	Reinvestment
148	Hällsjö-Söderala RL8 S4, S7 ledningsförnyelse	2020	2026	Over 500	Reinvestment
980	Rätan RT52 stationsförnyelse	2021	2026	Over 25	Reinvestment
831	Hammarforsen-avgr Svarthålforsen RL3 S2 ledningsförnyelse	2019	2027	Over 25	Reinvestment
832	Hammarforsen-Krångede RL3 S3 ledningsförnyelse	2019	2027	Over 25	Reinvestment
737	Hölleforsen IK6 stationsförnyelse	2022	2027	Over 25	Reinvestment
454	Laforsen-Hofors-Finnslätten RL7 S3-4 ledningsförnyelse	2020	2027	Approx. 1.5 billion SEK	Reinvestment
698	Ljusdal-Dönje-Ockelbo KL2 S4-5 ledningsförnyelse	2020	2027	Over 100	Reinvestment
829	Stadsforsen-Torpshammar RL2 S1 ledningsförnyelse	2019	2027	Over 100	Reinvestment
699	Ockelbo-Horndal KL2 S7-8 ledningsförnyelse	2020	2027	Over 250	Reinvestment
830	Svarthålforsen påstick-Stadsforsen RL3 S1 ledningsförnyelse	2019	2027	Over 25	Reinvestment
747	Moforsen AT68 stationsförnyelse	2023	2028	Over 5	Reinvestment
364	Grundfors-Norska gränsen-Gejmån AL7 S1-4, S9 topplinebyte	2026	2028	Over 5	Reinvestment
595	Grundfors-Ramsele UL5 S1-5 statusåtg	2025	2028	Over 5	Reinvestment
578	Järnvägsforsen avgr-Ånge RL22 S3 opto	2026	2028	Over 5	Reinvestment
577	Turinge - avgr Järnvägsforsen RL22 S2 topplinebyte	2025	2028	Over 5	Reinvestment
827	Krångede-Gammelänge KL4 ledningsförnyelse	2021	2028	Over 25	Reinvestment
519	Vittersjö CT33 EK3 stationsförnyelse	2024	2028	Over 25	Reinvestment
526	Vittersjö CT33 EK5 stationsförnyelse	2024	2028	Over 25	Reinvestment
893	Bräcke-Ljusdal KL1 S3-6 ledningsförnyelse	2022	2030	Over 500	Reinvestment
892	Krångede-Bräcke KL1 S1-2 ledningsförnyelse	2022	2030	Over 100	Reinvestment
855	Långbjörn-Lasele-Nämforsen, Betåsen-Lasele, AL6 S3, S4, S7, S8 ledningsförnyelse	2025	2031	Over 100	Reinvestment

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CONT. PROJECTS UNDER CONSIDERATION, SE2

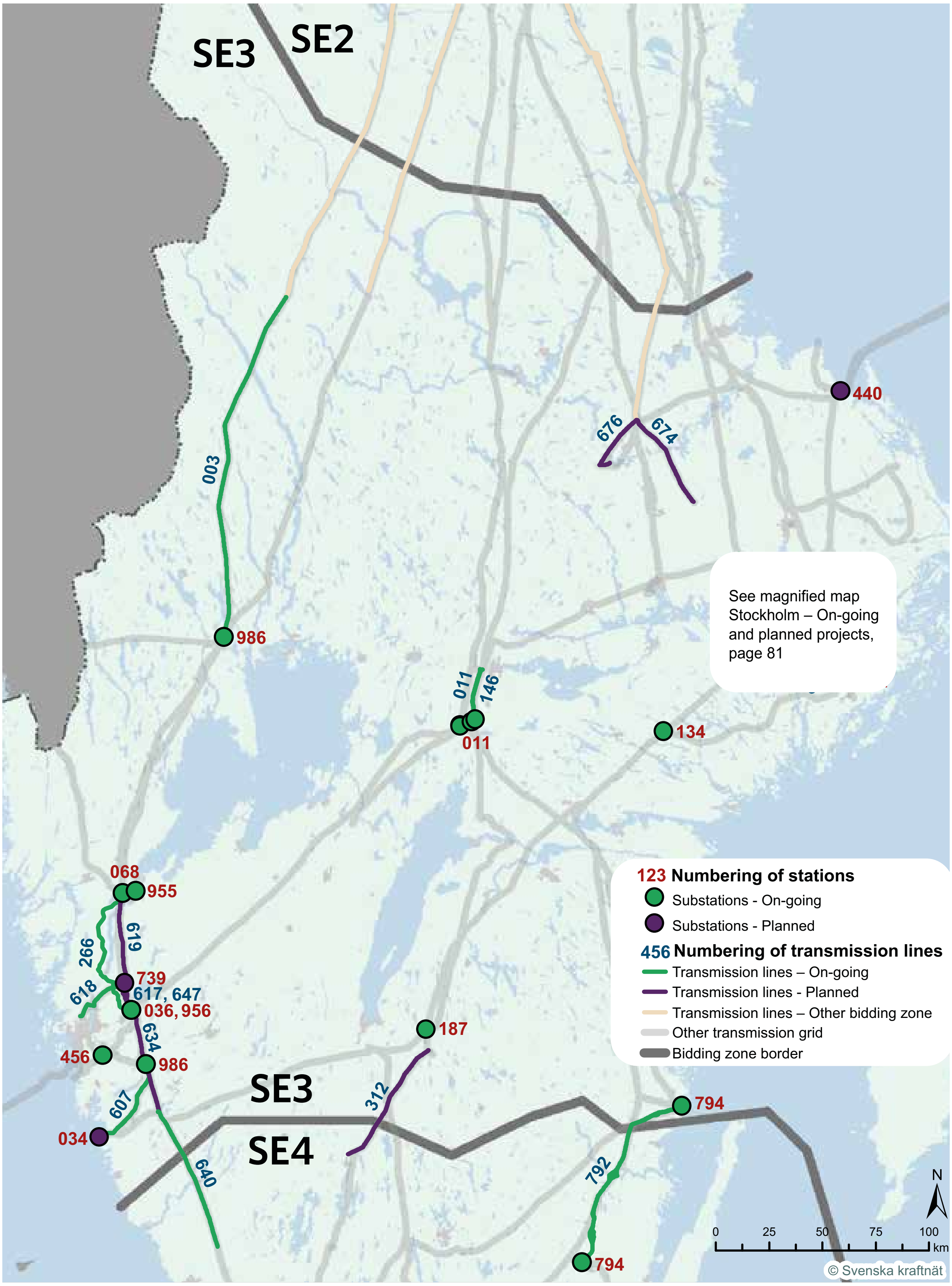
NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
854	Nämforsen-Forsmo AL6 S1-2, S9 ledningsförnyelse	2025	2031	Over 100	Reinvestment
848	Järkvissle avgr-Hällsjö RL8 S3 ledningsförnyelse	2025	2032	Over 100	Reinvestment
846	Stadsforsen-Hölleforsen RL8 S1 ledningsförnyelse	2027	2033	Over 5	Reinvestment
850	Stadsforsen-Hjälta kraftstation AL4 ledningsförnyelse	2027	2034	Over 100	Reinvestment

PHOTO: TOMAS ÅRLEMO

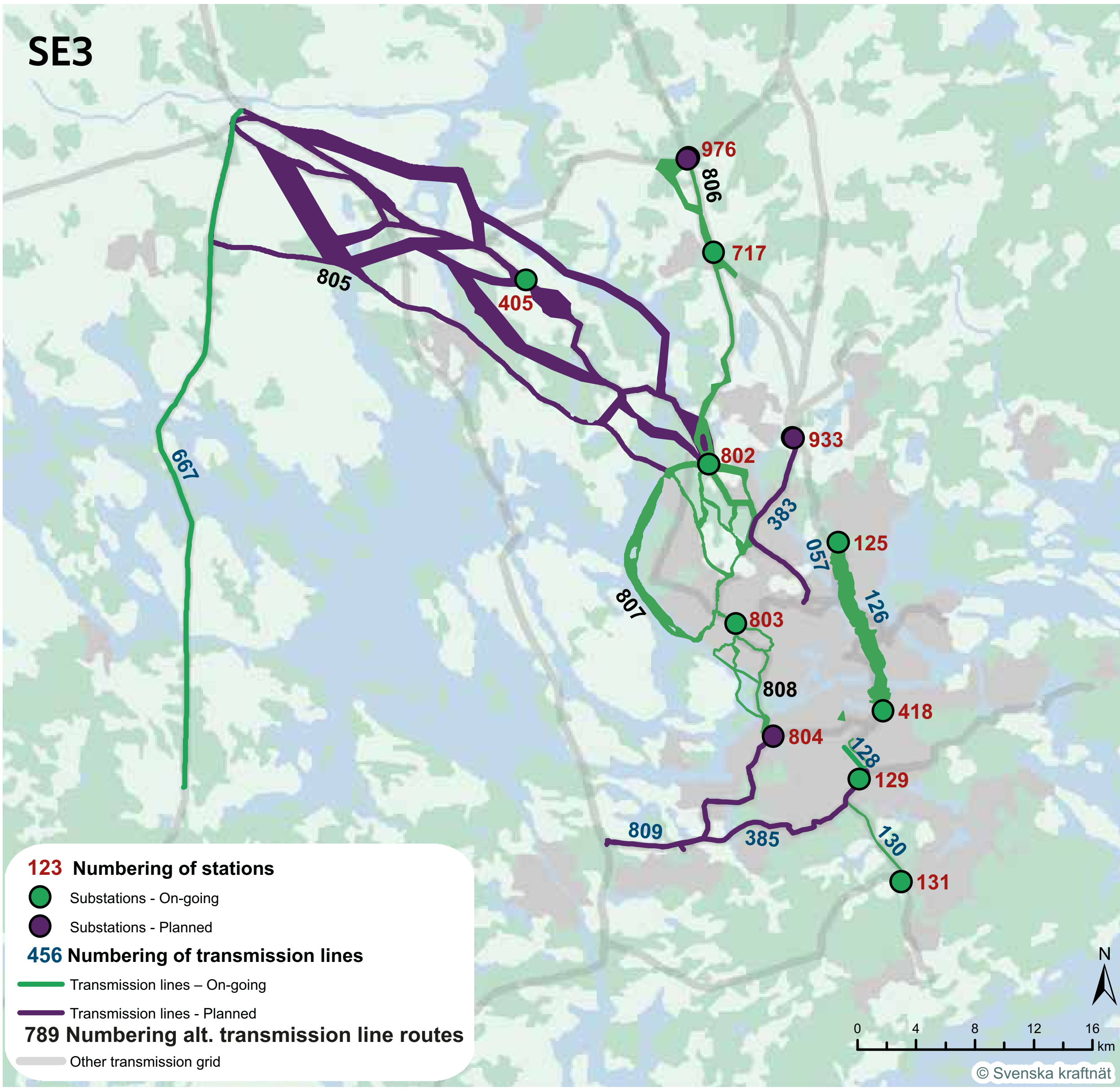
B.3 Bidding zone Stockholm (SE3)

ON-GOING PROJECTS SE3

NO	PROJECT	COMMISSIONING	COST (MSEK)	DRIVING FORCE
187	SydVästlänken Barkeryd DC	2018	1 030	Market Integration
125	Anneberg Ny reaktor	2018	25	System Reinforcement
986	Installation av shuntkondensatorer i Borgvik och Strömma	2018	40	System Reinforcement
717	Måby, anslutning av ny 220/70 kV-transformator	2018	10	Connection
057	Anneberg-Danderyd anslutningsåtgärder	2018	10	System Reinforcement
036	Utbyggnad av 400 kv-ställverket Stenkullen	2020	45	System Reinforcement
956	Stenkullen, reaktiv produktion	2020	260	System Reinforcement
146	Lindbacka-Östansjö ny 400 kV-ledning	2020	270	System Reinforcement
011	Avveckling av 220kV nätet kring Hallsberg	2020	35	System Reinforcement
131	Ekudden Station	2021	200	System Reinforcement
266	Skogssäter-Stenkullen ny 400 kV-ledning	2021	900	System Reinforcement
130	Snösätra-Ekudden Luftledning	2022	130	System Reinforcement
128	Örby-Snösätra Markkabel	2022	400	System Reinforcement
418	Skanstull Station	2022	500	System Reinforcement
129	Snösätra, ny transformatorstation	2022	400	System Reinforcement
794	Ekhyddan-Nybro-Hemsjö stationsåtgärder	2023	75	Market Integration
792	Ekhyddan-Nybro ny 400 kV-ledning	2023	880	Market Integration
126	Anneberg-Skanstull tunnelkabel	2026	2 830	System Reinforcement
803	Beckomberga ny 400 kV-station	2027	450	System Reinforcement
802	Överby ny 400 kV-station	2027	300	System Reinforcement
806	Odensala-Överby ny 400 kV-ledning	2027	570	System Reinforcement
807	Överby-Beckomberga ny 400 kV-ledning	2027	1 230	System Reinforcement
808	Beckomberga-Bredäng ny 400 kV-ledning	2027	1 000	System Reinforcement
955	Stallbacka ZT71 stationsåtgärder	2018	10	Reinvestment
618	Kilanda-Hisingen CL29 opto	2018	10	Reinvestment
667	Hamra-Åker CL3 S5 ombyggnad över Mälaren	2018	55	Reinvestment
	Uppgradering av kommunikationskanaler för längsdifferentialskydd	2018	5	Reinvestment
456	Konti-Skan 1 o 2 kontrollanläggningsförnyelse	2019	230	Reinvestment
134	Hedenlunda CT35 stationsförnyelse	2019	150	Reinvestment
068	Skogssäter CT15 stationsförnyelse	2019	270	Reinvestment
607	Strömma-Ringhals FL66-68 statusåtg	2019	45	Reinvestment
617	Kilanda-Stenkullen CL32 S1-3 opto	2019	10	Reinvestment
003	Tandö-Borgvik CL26 S5-6 statusåtg	2020	15	Reinvestment
640	Horred-Breared FL14 S3-4 ledningsförnyelse	2028	810	Reinvestment



Project overview SE3, on-going and planned



Project overview Stockholm, on-going and planned

PHOTO: MAGNUS MIKAELSSON

PLANNED PROJECTS SE3

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK	DRIVING FORCE
933	Hagby CT65 ny 400/130 kV-anslutning	2018	2021	Over 25	Connection
976	Odensala CT68 ny 400/130 kV-transformator	2018	2022	Over 5	Connection
805	Hamra-Överby ny 400 kV-ledning	2018	2027	Over 500	System Reinforcement
804	Bredäng ny 400 kV-station	2020	2027	Over 250	System Reinforcement
809	Bredäng-Kolbotten ny 400 kV-ledning	2025	2030	Over 25	System Reinforcement
312	Förv.projekt Uppgräv.av fundament 220kV led.KL15 S1 Nässjö-Värnamo	2017	2019	Over 25	Reinvestment
634	Stenkullen-Horred CL32 S4-6 ledningsförnyelse	2017	2022	Over 250	Reinvestment
676	Horndal - Avesta KL13 S1 ledningsförnyelse	2018	2022	Over 100	Reinvestment
739	Kilanda CT267 stationsförnyelse	2019	2022	Over 100	Reinvestment
674	Horndal-Starfors KL12 S1 ledningsförnyelse	2018	2023	Over 100	Reinvestment
440	Forsmark FT47 stationsförnyelse	2018	2023	Over 100	Reinvestment
385	Lindhov-Högdalen Rivn KL23 inkl omkoppl Hågelby	2019	2023	Over 5	Reinvestment
034	Ringhals VK51 stationsförnyelse	2018	2024	Over 100	Reinvestment
619	Skogssäter-Kilanda FL5 S7-8 ledningsförnyelse	2017	2024	Over 250	Reinvestment
647	Kilanda-Stenkullen FL5 S5-6 och CL32 S1-3 förnyelse	2017	2026	Aprox. 2.5 billion SEK	Reinvestment
383	Hagby-Järva Rivning RL15/RL17	2019	2027	Over 5	Reinvestment

PROJECTS UNDER CONSIDERATION, SE3

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
424	Shuntkompensering snitt 2	2018	2020	Over 100	Market Integration
953	Kolbotten FT41 nya 400/130 kV-transformeringar	2018	2021	Over 5	Connection
442	Hagby, Hamra, Kolbotten - reinvestering dynamiska spänningsreglerresurser	2020	2027	Over 100	System Reinforcement
762	Åker CT30 stationsförnyelse	2019	2022	Over 25	Reinvestment
735	Horndal RT24 stationsförnyelse	2018	2023	Over 100	Reinvestment
740	Kolstad FT92 stationsförnyelse	2019	2023	Over 25	Reinvestment
301	Bäsna CT23 stationsförnyelse	2019	2024	Over 100	Reinvestment
065	Kimstad CT36 stationsförnyelse	2019	2024	Over 100	Reinvestment
516	Djurmo CT22 EK2 stationsförnyelse	2020	2024	Over 25	Reinvestment
270	Hallsberg - Kimstad CL4 S5 Ledningsflytt	2018	2024		Reinvestment
268	Höjning FL1 S1-3, FL6 S1-2 vid Göta kanal	2018	2024		Reinvestment
733	Himmeta RT63 stationsförnyelse	2020	2024	Over 5	Reinvestment
611	Kolstad-Barkeryd-Tenhult FL9 S3-4 opto	2021	2024	Over 5	Reinvestment
730	Glan CT38 stationsförnyelse	2020	2024	Over 100	Reinvestment
522	Kättbo CT13 EK1 stationsförnyelse	2021	2025	Over 25	Reinvestment
612	Stenkullen-Strömma FL18 S1-2 opto	2022	2025	Over 5	Reinvestment
615	Horred-Häradsbo FL12 S1-2 opto	2022	2025	Over 5	Reinvestment
610	Glan-Kolstad FL9 S2 opto	2023	2025	Over 5	Reinvestment
682	Horndal-Finnslätten RL2 S5 ledningsförnyelse	2018	2025	Over 250	Reinvestment
021	Tuna CT63 220 kV stationsförnyelse	2020	2025	Over 25	Reinvestment
623	Tenhult-Alvesta FL9 S5-6 opto	2023	2026	Over 5	Reinvestment
767	Gustafs CT72 stationsförnyelse	2022	2026	Over 25	Reinvestment
732	Hall FT81 stationsförnyelse	2021	2026	Over 100	Reinvestment
746	Malsta RT192 stationsförnyelse	2021	2026	Over 25	Reinvestment
299	Tenhult FT188 stationsförnyelse	2021	2026	Over 100	Reinvestment
614	Strömma-Horred FL14 S1-2 opto	2022	2027	Over 5	Reinvestment
728	Finnslätten RT25 stationsförnyelse	2022	2027	Over 25	Reinvestment
353	Hagby CT65 220 kV stationsförnyelse	2022	2027	Over 25	Reinvestment
677	Untra-Bredåker KL21 S1 ledningsförnyelse	2020	2027	Over 250	Reinvestment
759	Valbo RT84 stationsförnyelse	2022	2027	Over 25	Reinvestment
685	Valbo-Untra RL8 S5 ledningsförnyelse	2020	2027	Over 100	Reinvestment
518	Tandö CT261 EK6 stationsförnyelse	2023	2027	Over 25	Reinvestment
608	Hallsberg-Timmersdala-Stenkullen FL5 S1-4 opto	2024	2027	Over 25	Reinvestment
241	Horred-Uddebo-Tenhult FL18 S5-8 opto	2024	2027	Over 25	Reinvestment
245	Hedenlunda-Glan CL3 S8 opto	2026	2028	Over 5	Reinvestment
017	Kolbotten FT41 400 kV stationsförnyelse	2023	2028	Over 100	Reinvestment
613	Strömma-Lindome-Billdal FL2 S1-4 opto	2023	2028	Over 5	Reinvestment
757	Timmersdala FT52 stationsförnyelse	2023	2028	Over 25	Reinvestment
658	Edinge-Gråska RL11 S3-4 opto	2025	2028	Over 5	Reinvestment
659	Kolbotten-Hall-Hedenlunda FL8 S1-4 opto	2025	2028	Over 5	Reinvestment
679	Måby-Hagby KL41 S4-6 ledningsförnyelse	2019	2028	Over 25	Reinvestment
664	Odensala-Kolbotten FL4 S1-4 opto	2025	2028	Over 5	Reinvestment
673	Horndal-Untra KL11 statusåtg och opto	2021	2028	Over 100	Reinvestment

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Project overview SE3, under consideration

CONT. PROJECTS UNDER CONSIDERATION, SE3

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
723	Bredåker RT87 stationsförnyelse	2024	2029	Over 25	Reinvestment
700	Bredåker-Överby/Avgr Måby KL42 S1-8 ledningsförnyelse	2023	2030	Over 250	Reinvestment
662	Finnslätten-Himmeta RL6 S7 opto	2027	2030	Over 5	Reinvestment
665	Hallsberg-Lindbacka CL22 S7 opto	2027	2030	Over 5	Reinvestment
660	Hamra-Odensala CL11 S3-5 opto	2027	2030	Over 5	Reinvestment
663	Himmeta-Lindbacka RL6 S3 opto	2027	2030	Over 5	Reinvestment
727	Edinge RT112 stationsförnyelse	2026	2031	Over 5	Reinvestment
145	Lindbacka RT16 400 kV stationsförnyelse	2026	2031	Over 100	Reinvestment
686	Untra-Bredåker RL8 S6 ledningsförnyelse	2026	2033	Over 250	Reinvestment
672	Bäsna-Hallsberg CL44 S5-7 ledningsförnyelse	2025	2035	Approx. 1.5 billion SEK	Reinvestment
683	Hamra-Finnslätten RL6 S4 ledningsförnyelse	2027	2035	Over 100	Reinvestment

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B.4 Bidding zone Malmö (SE4)

ON-GOING PROJECTS SE4

NO	PROJECT	COMMISSIONING	COSTT (MSEK)	DRIVING FORCE
191	SydVästlänken Hurva DC	2018	1 060	Market Integration
787	NordBalt - Markkabel skarvbyten	2018	15	Market Integration
425	Hurva-Sege FL24 S3-4 ledningsförnyelse	2021	400	Market Integration
793	Nybro-Hemsjö ny 400 kV-ledning	2023	950	Market Integration
794	Ekhyddan-Nybro-Hemsjö stationsåtgärder	2023	75	Market Integration
367	Hansa PowerBridge - Sjökabel	2026	950	Market Integration
368	Hansa PowerBridge - Land	2026	940	Market Integration
372	Hansa PowerBridge HVDC-Station	2026	1 240	Market Integration
371	Döshult ledningsflytt	2018	15	Reinvestment
626	Kristinelund-Söderåsen FL23 opto	2018	15	Reinvestment
978	Söderåsen FT12 ledningsåtgärder	2018	15	Reinvestment
973	Söderåsen FT12 förnyelse reaktor X1	2018	15	Reinvestment
300	Barsebäck FT76 stationsförnyelse	2019	110	Reinvestment
341	Utbyte av Öresundskablarna 400 kV	2019	370	Reinvestment
791	Staffanstorp ledningsflytt FL7 S7-8	2021	25	Reinvestment
652	Breared-Söderåsen FL7 S3-4 ledningsförnyelse	2029	1 040	Reinvestment

PLANNED PROJECTS, SE4

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
654	Sege-Barsebäck FL7 S7-8 ledningsförnyelse	2018	2025	Over 250	Reinvestment

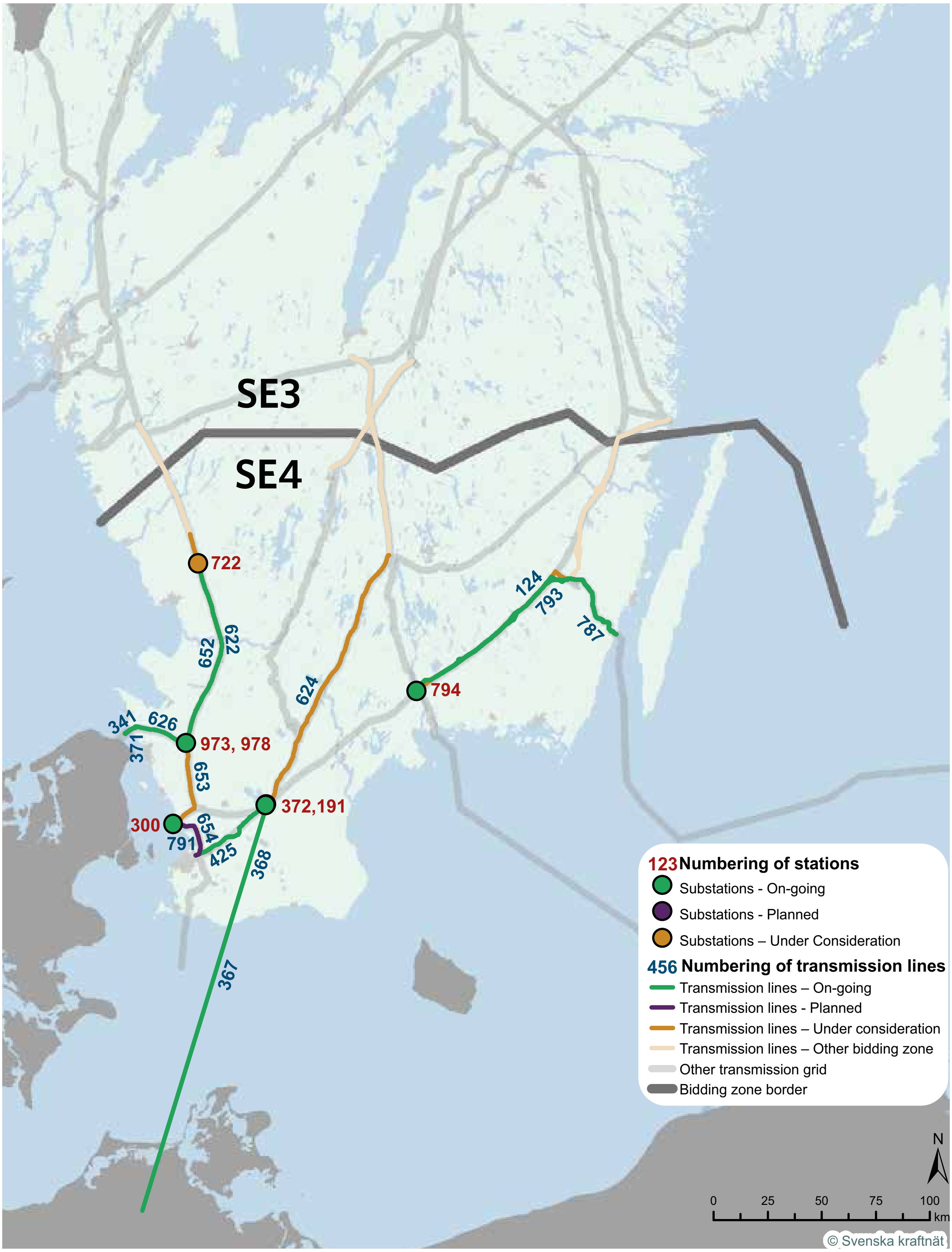
PROJECTS UNDER CONSIDERATION, SE4

NO	PROJECT	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
124	Nybro-Hemsjö FL6 S4 topplinebyte	2021	2024	Over 25	Reinvestment
622	Häradsbo-Söderåsen FL12 S3-4 opto	2023	2025	Over 5	Reinvestment
624	Alvesta-Hurva FL24 S1-2 opto	2023	2026	Over 5	Reinvestment
653	Söderåsen-Barsebäck FL7 S5-6 ledningsförnyelse	2020	2028	Over 250	Reinvestment
722	Breared FT72 stationsförnyelse	2027	2030	Over 100	Reinvestment

B.5 Project SE1-SE4

PROJECT SE1-SE4

NO	PROJECT	CATEGORY	PROJECT START	COMMISSIONING	COST (MSEK)	DRIVING FORCE
	Utbyte av DTN - del 2 (SE1-SE4)	On-going		2018	50	Reinvestment
	Stationsanpassning - Fjärrkontrollterminaler (SE1-SE4)	On-going		2018	80	Reinvestment
	Förv.projekt Primärapparater 2018-2020 (SE1-SE4)	On-going		2020	20	Reinvestment
	Förnyelse kontrollanläggningar 2018-2021 (SE1-SE4)	On-going		2019-2021	170	Reinvestment
	Kontrollanläggningsåtgärder shuntreaktorer (SE1-SE4)	Under consideration	2017	2019	Over 5	Reinvestment
	Uppgradering av TPE och avveckling av PDH (SE1-SE4)	Under consideration	2017	2020	Over 5	Reinvestment
	Förnyelse kontrollanläggningar 2022-2025 (SE1-SE4)	Under consideration	2020	2025	Over 25	Reinvestment
	Förnyelse kontrollanläggningar 2026-2030 (SE1-SE4)	Under consideration	2025	2030	Over 100	Reinvestment



Project overview SE4

BIDDING ZONES

THE TRANSMISSION GRID

The Swedish transmission grid consists of 15,000 km power lines, 160 transformation and switching stations and 16 interconnections.

Our society is dependent on electricity. Svenska kraftnät is responsible for ensuring that Sweden has a safe, environmentally sound and cost-effective transmission system for electricity – today and in the future. We achieve this in the short term by monitoring the electrical system around the clock, and in the long term by building new power lines to meet tomorrow's electricity needs.

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