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# Abstract

The structure of the Swedish power grid results in energy flows called national transit, due to the high level of interconnections within the power grid. National transit is defined as electrical power entering an underlying grid from the national grid, only to later re-enter the national grid without being consumed within underlying grid. This results in additional loads, and therefore losses and costs, for the owners of the underlying grids. Svenska kraftnät is the state owned public utility appointed by the government to operate and manage the national grid. Actors connected to the national grid pay a grid tariff for their input and output in each connection point. As part of this tariff an economic compensation can be appointed to grid owners subject to extensive national transit. This is done through accepting so called connection point joint subscriptions for several connection points between the national grid, and a regional grid, resulting in lower subscription costs. The current compensation model is an exception from the normal grid connection tariff and has to be applied for separately. It is considered inefficient and therefore there is a desire to review the model for compensation.

This project aims at presenting recommendations for a future compensation model. The outcome of the project is three different technical bases for compensation, further related to different models for economic compensation. In addition to this, a reformation of the current model is presented and analyzed, as well as the effects of removing compensation completely. The technical bases are validated through four different cases based on actual areas within the Swedish national power grid. The first model is based on actual transit occurring through regional grids and requires a large amount of data collected from the connection points within the regional grids. This information is currently collected to some extent but not enough to enable calculations of the actual transit. The second model is based on the added value created through increased transmission capacity by regional power lines in parallel with the national grid across different bidding areas and in connection to international connection points. The calculation of added value within this model is made based on systems and programs already in place at Svenska kraftnät today. The third model handles the variation in input and output for individual connection points within a regional grid, caused by activities on the national grid such as import and export from neighboring countries. Two of the technical bases, compensation for increased transmission capacity and variation in input and output, are viable with currently available data and system models. Out of these, one compensates for the costs for regional grid owners associated with activity on the national grid, such as national transit, and the other compensates for added value for Svk. Which model is the most suitable depends on the desired reason for compensation.

# Sammanfattning

Det svenska elnätets uppbyggnad resulterar i energiflöden mellan stam- och regionnät kallade nationell transit, som följd av maskning av nätet. Nationell transit är definierat som elektricitet som flödar från stamnätet, genom ett underliggande nät, för att sedan åter flöda till stamnätet utan att användas i det underliggande nätet. Detta ger en ökad last, och därmed ökade förluster och kostnader, för ägarna av det underliggande nätet. Svenska kraftnät är det affärsverk som på uppdrag av regeringen ansvarar för att sköta, underhålla och utveckla det svenska stamnätet. Samtliga abonnenter anslutna till stamnätet betalar en stamnätstariff för in- och utmatning i samtliga anslutningspunkter. Som en del denna tariff finns en ekonomisk kompensationsmodell, kallad summaabonnemang, vars syfte är att kompensera regionnätsägare med omfattande nationell transit. Kompensationen sker genom att flera anslutningspunkter mellan regionnät och stamnät kan tilldelas ett gemensamt abonnemang, ett så kallat summaabonnemang, som då innebär en rabatt på abonnemangskostnaden. Detta är ett undantag som kan beviljas då ett underliggande nät påverkas av transit i stor utsträckning och måste ansökas om separat. Den nuvarande kompensationsmodellen anses vara bristfällig och det finns därför en vilja att uppdatera den.

Projektet syftar att presentera rekommendationer för en framtida kompensationsmodell för nationell transit. Rapporten presenterar tre möjliga tekniska baser för kompensation, samt ekonomiska modeller för kompensation relaterade till varje teknisk bas. Utöver detta så utvärderas även en uppdaterad version av dagens modell, samt konsekvenser av att helt ta bort kompensation för nationell transit. De tekniska kompensationsbaserna valideras genom fyra fallstudier baserade på faktiska data för områden inom det svenska elnätet. Den första tekniska kompensationsbasen innebär en kompensation för faktisk transit genom regionnät och kräver omfattande data från anslutningspunkter inom regionnäten. I dagsläget insamlas denna data till viss del, men inte i tillräckligt stor utsträckning för att möjliggöra beräkningar baserat på detta. Den andra tekniska kompensationsbasen baseras på den nytta som tillförs från regionnätsledningar till stamnätets överföringskapacitet genom att löpa parallellt med särskilt belastade stamnätsledningar, lokaliserade vid internationella förbindelser och över snitt mellan elområden. Dessa nyttoberäkningar baseras på idag tillgängliga program och system. Den tredje tekniska kompensationsbasen utgår från den variation i uttag och inmatning som sker i enskilda anslutningspunkter inom ett regionnät, på grund av aktiviteter på stamnätet så som import och export från grannländer. Två av de tekniska kompensationsbaserna, kompensation för nytta från regionnätsledningar och variation i uttag och inmatning, kan användas med data och systemmodeller som idag finns tillgängliga hos Svk. Av dessa kompenserar den ena för ökade kostnader för regionnätsägare medan den andra belönar nytta som skapas för Svk. Vilken av modellerna som är mest lämplig beror därför på vilket syfte som avses med kompensationen.

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Thank you,

Linn Fröström & Therese Hedberg Lundblad
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# Innehåll

## Abbreviations

| | |
|---|---|
| DSO | Distribution System Operator |
| Ei | Energimarknadsinspektionen |
| ENTSO-E | European Network of Transmission System Operators for Electricity |
| EU | European Union |
| IPS/UPS | Integrated Power System/Unified Power System |
| ITC | Inter-TSO Compensation |
| JS | Joint subscription |
| N | National grid power line |
| R | Regional grid power line |
| Svk | Svenska kraftnät |
| SWOT | Strengths, Weaknesses, Opportunities and Threats |
| TSO | Transmission System Operator |

## Nomenclature

| **Variable** | **Unit** | **Description** |
|---|---|---|
| C | SEK | Cost |
| c | SEK/kW | Capacity charge |
| L | kW | Vertical load |
| m | - | Month |
| NEF | kW | Net Export Flow |
| NIF | kW | Net Import Flow |
| P | kW | Power |
| T | kW | Transit |
| | | |
| $\Delta$ | - | Difference |
| $\sigma$ | - | Standard deviation |

# 1 Introduction

The modern society depends on a stable and secure electricity supply. Several vital elements of society, such as fresh water production, medical care and food preservation cannot function without access to electricity (Martin 2015). Dependable electricity production, transmission and distribution is in turn of vital importance for electricity supply security since electricity has to be consumed at the same instant as it is produced, and production and consumption can occur in different geographic locations (Vattenfall 2013).

The Swedish electricity market can be divided into two sections, the physical and the financial market. Electricity is generated by producers and then transmitted to the final consumers. In order to transmit the electricity, a power grid is required. A large share of the Swedish electricity generation is located in the northern part of the country, as the availability of hydropower is high in this region. Meanwhile, the largest demand is located further south as the population density is greater there, resulting in a great deal of electrical power transmitted through the country. The amount of transmitted power and its direction depends greatly on how electricity is generated and where electricity is consumed, and was for example affected by low electricity supply from hydro and wind power in 2016 (Lindholm 2017). The power grid and its operation, balancing and management, as well as the electricity generation and consumption are considered the physical aspect of the electricity market. The financial aspect is related to the trade on the Nordic market Nord Pool where electricity is sold and purchased based on the demand and production (Federal Energy Regulatory Commission 2015). Svenska kraftnät, *Svk*, is the transmission system operator, *TSO*, in Sweden. They are responsible for operation and maintenance of the national grid as well as frequency balancing in the grid ([A]Svenska kraftnät 2016). Svk is a state owned public utility operating on behalf of the Swedish government with responsibility to ensure a reliable, well-functioning electricity grid ([A]Svenska kraftnät 2017). Grid stability is further improved through international connections, both to the neighboring countries and to continental Europe. Within the European Union, *EU*, there are policies promoting further improvement of inter-country grid connections to improve the overall grid stability and market conditions ([A]European Comission 2017).

The Swedish national power grid is an interconnected network, meaning that regional grids can be connected to the national grid in more than one connection point. Electricity transmitted through the national grid selects the pathway with the lowest impedance at that instance which results in that some electrical power can go through a regional grid if it has more than one connection point to the national grid. This is referred to as national transit. National transit is by Svk defined as electrical power entering an underlying grid only to later re-enter the national grid without being consumed within the underlying grid. Regional grid owners apply for permission to connect to the national power grid and pay a yearly subscription based on the maximum capacity for input and output desired for each connection point, as well as the energy flow through the connection point. Due to the structure of the grid tariff the regional grid owners' costs increase when national transit occurs through their grids. As a way to compensate for the economic losses, some of the regional grid owners with the largest transit costs can be given a specific subscription type in which several connection points could be billed as if they were one connection point when applying for allowance for maximum input and output capacity (Nilsson & Guldbrand 2017). A separate application has to be submitted for this, and is approved if the effect from transit is large enough according to Svk's measures. The compensation is an exception from the normal tariff.

A highly interconnected power grid enables the electricity to travel several pathways through the grid as it is transmitted from north to south. The increase in alternative pathways results in a stable grid and an increase in security of supply, one of the targets the government in cooperation with Svk is continuously working towards. Therefore, it could be socioeconomically efficient to incentivize the regional grid owners to further develop their grids at the same pace as that of the national grid in order to enable for a sustainable and stable power grid in the future.

## 1.1 Problem identification

Based on experience and analyses made by Svk, it has been concluded that the current model for compensation of national transit through regional grids is not well structured or fulfilling its purpose sufficiently. Gathering several connection points in what can be modeled as one connection point results in complications both in technical and financial management of the grid. Problems arise when Svk plans the development of the national grid. Since several connection points have a joint maximum capacity level, and development plans are constructed for worst case scenarios, the dimensioning and development of the grid has to be planned such that the maximum capacity to these joint connections could be supplied through either of the connection points alone. Furthermore, having exceptions to the standard subscription types leads to more work for the financial department, as they have to handle the joint connection points separately and manually. The current method also lacks a well-defined transit limit for when it is granted.

A highly interconnected grid offers alternative routes for power as it is transmitted through the country. Therefore, the access to regional grids for transit can contribute to social welfare as it increases the capacity for transmission through the country, resulting in increased grid stability. Transit on regional grids causes additional load and as a result increased costs. As this creates inequity between regional grid owners, there is an incentive to compensate the owners of regional grids to create a fair market model and ensure continued construction of interconnected grids where needed and judged socioeconomically feasible. As the current compensation model is considered insufficient with regards both to physical aspects, such as the management and development of the grid, and financial aspects, the development of a new model for economic compensation of regional grid owners is judged relevant for future work at Svk.

## 1.2 Objectives

The overall objective of this project is to develop and present an economic compensation model which compensates owners of regional grids as national transit is conducted through these. The model should be just and objective. Furthermore, the current model results in an additional workload for calculations of energy flows as well as for financial estimations. The development of a new model should therefore, if possible, decrease the workload. There is a desire within Svk to continue compensating owners of regional grids for national transit, as it is a way to make the tariff more fair, objective and non-discriminating. Within the scope of the project, two parts can be distinguished; an analysis of the current situation and the development of new methods for compensation. The new models for compensation include both a technical basis for compensation, as well as an economic model describing the allocation of capital.

The long-term outcome of the economic compensation model is to create fair, objective and non-discriminating market conditions for all users. In terms, this should create an incentive for increased development of the regional grids in line with the development of the surrounding environment as well as the national grid. The model should serve as a basis for a collaborative approach towards increased security of supply through government, motivation and confirmation. By awarding an economic compensation, regional grid owners are governed in the right direction when investing in grid development. Furthermore, it offers motivation for continuous improvement and calls attention to desired positive behavior. The model should be based on the assumption that it is not required for the continued work of the regional grid owners, but rather a reward for the service of increased grid stability and therefore the security of supply for all final consumers.

## 1.3 Limitations

The project is limited to national transit occurring between the national grid and underlying regional grids in Sweden. The system is subject to surrounding conditions and therefore the model is adapted to such. The model should, if possible, be based on measured values available at Svk as data supplied by owners of regional grids may be biased. The model should not require any additional administrative handling as compared to the current model. The structure of the national grid tariff is assumed to be unchanged and outside the scope of the project, except for the joint subscriptions. Focus lies in finding methods that can be used for economic compensation, and comparing these. The size of the actual compensation capital to be allocated between the regional grid owners is not to be established in this report. Finally, as the data used for calculations is based on actual activities on the national grid in Sweden and therefore classified, only trends are presented in this report.

## 1.4 Research method

In order to meet the objectives of the project, a combination of literature review, interviews, technical modeling and SWOT analyses are used. The literature review and interviews combined are used to establish the current situation and are the base for modeling. This stage also collects the input data necessary for the system modeling. The current situation is analyzed both nationally and internationally in order to provide insight into existing solutions. Interviews are conducted mainly within Svk, but to some extent with representatives for regional grid owners and other TSOs as well. The internal interviews are made with the purpose of collecting information and opinions on the current compensation model as well as desired features and improvements for future models. The purpose of the external interviews is to collect opinions from the regional grid owners on what the current compensation model contributes with.

After collection of information regarding the system and surrounding environment, the compensation model used today is analyzed in terms of compensation cost and structure to conclude its efficiency and future prospects. This is presented in the first part of the project in Section 3. This part also includes information gathered from interviews related to the current model. The second part of the project, presented in Section 4 and 5, contains the modeling of new compensation models and an evaluation of their applicability. The second part of the project is based on findings from the first part and the literature review in combination with innovative ideas developed throughout the analysis. Finally, a conclusion is made based on the two parts as well as the results of the validation of applicability, and future recommendations are presented. This is presented in Section 6 and 7.

# 2 The electricity market and its components

This section describes the main components of the Swedish electricity system, Svk's role in it, the European electricity system and current compensation models for national transit in Sweden and a selection of European countries.

## 2.1 The Swedish electricity market

The Swedish electricity market is deregulated and unbundled, meaning that the electrical transmission and distribution is separated from electricity generation. This is in accordance with the Third Energy Package, presented by the EU in 2007 and adopted in 2009, which also contains rules for regulator independency ([B]European Commission 2017). The Swedish electricity system has been unbundled since 1996 in order to promote more efficient electricity supply, and increased freedom of choice for electricity users. There is a free market for electricity production and consumption, while distribution is regulated. Distribution companies are not subject to competition within their respective operational areas since having multiple distribution companies in one area is inefficient. It is therefore not possible to choose which grid to connect to, and the power grid can be regarded as a natural monopoly. The nature of the grid induces the requirement of regulation, therefore there is a third party monitoring the activities of the grid owners. In Sweden, the monitoring is performed by the Energy Market Inspectorate, *Ei* ([A]Svenska kraftnät 2014).

The electricity market can be split into physical and financial regulation. For consumers this is visible through the two prices paid for electricity, one for the electrical power and one for distribution ([A]Svenska kraftnät 2014). Physical regulation of electricity markets include electricity distribution and balancing of the electricity grid. Constant electricity access in all regions is ensured by the TSO, which is an organization appointed by the government to keep the national grid electrically stable. The Swedish national electricity grid is owned and operated by Svk, a state owned public utility. They are responsible for ensuring that electricity production and demand is balanced at all times, and to develop and maintain the electricity transmission grid in Sweden so that electricity can flow between production units and consumers. Since they are not subject to competition, their operations are regulated ([A]Svenska kraftnät 2016).

In Sweden electricity is purchased and traded on the power market Nord Pool where retail companies trade electricity through purchase from producers and selling it to consumers. Nord Pool is jointly owned by the Nordic and Baltic TSOs, and was founded to create better conditions for consumers through providing an open marketplace for power trading ([A]Nord Pool 2017; [A]Svenska kraftnät 2014). The market is split into a spot market for intraday trading, and a market for day-ahead trading. The prices in the day-ahead trading are set through auctions, while the intraday trading prices may vary during the trading period ([B]Nord Pool 2017). In 2011, Sweden reformed the structure of its energy market and divided the country into four different bidding areas. The division into areas was made in order to handle the transmission limitations of the grid due to large volumes of production in the northern parts of the country with relatively high consumption in the southern parts, in a more market based manner ([A]Svenska kraftnät 2014). The different bidding areas can at times have different electricity prices. The difference in price sends clear signals to the market as to where production should increase. It also signals to Svk where increased transmission capacity is required. Furthermore, the division into bidding areas was made to meet the requirements of the EU for open and accessible trade of goods and services within the union (Energimarknadsinspektionen 2014). The areas are shown in Figure 1.


Figure 1. Sweden's bidding areas, with names and boundaries (Based on [A]Svenska kraftnät 2016).

Before the division into bidding areas, the limitations in transmission capacity were handled through limiting the export of electricity when parts of Sweden were facing the threat of an electricity shortage, therefore affecting neighboring countries. Through the implementation of bidding areas, the price of electricity should instead increase in the case of a power deficit resulting in a decreased demand due to limited willingness to pay as the price increases above a certain limit (Energimarknadsinspektionen 2014).

Limitations in transmission capacity are unavoidable as it is not economically feasible to construct power lines with capacity to cover every peak of transmission. Therefore it is instead necessary to manage the grid during hours of congestion which occurs when a section of the grid is utilized at its full capacity. Congestion management is part of the TSO's responsibility. The division of the Swedish electricity market into different bidding areas enables for the use of the same congestion management method as is used for trade between countries on Nord Pool. The method is called market splitting and involves the division of the market into different areas, such as the bidding areas. Within each Swedish bidding area, actors offer electricity to the market at different prices depending on their marginal cost of production. The TSO then purchases electricity in the area with a surplus and sell to the area with a deficit at the available capacity of the interconnector between the areas. Due to the limitation in transmission capacity of the interconnector electricity in the area with a deficit is produced at a higher cost than in the other bidding area. This results in different electricity prices in the two areas as the market closes. Furthermore, as the electricity is purchased by the TSO in the cheaper area and then sold in the area with the higher price, the TSO gains revenues from the congestion management (Svenska kraftnät 2009).

## 2.2 The electricity act

The legal requirements of all actors active on the electricity market in Sweden are presented in the electricity act (SFS 1997:857). A set of sections in the electricity act are of importance when formulating a compensation model for national transit and when establishing the basis and reason for compensation. Chap. 3, 1§ of the electricity act specifies that each actor that conducts a network operation, such as the TSO and regional grid owners, are responsible for the operation and maintenance of their grid. They are also responsible for, when required, the development and extension of the grid network within it. The actor is to ensure that the network is safe, reliable and efficient and that the transmission of electricity is secure in the long term (SFS 2005:404). Furthermore, chap. 3, 10§ describes the obligations of metering and reporting of electrical power transmitted from each actor that conduct network operation. It is stated that each actor should meter and report the power transmitted and its distribution over time, and that the information is to be shared with the government or the authority appointed by the government. The government, or appointed authority, is responsible for regulation of the system for metering and reporting (SFS 2017:196).

The national grid tariff is regulated through the electricity act which, in chap. 4, 1§, states that all tariffs should be objective and non-discriminating, and further establishes a framework for revenues resulting in a fair cost (SFS 2014:270). The electricity act does not state any requirements of economic compensation for national transit and regional grid owners are permitted to structure their grid as preferred as no other requirements are stated. However, previously mentioned laws are to be incorporated in the planning and development.

The authority appointed by the government to regulate the metering and reporting of electrical power transmitted is Ei. The regulations are summarized in an injunction updated on a regular basis which presents the specifics of the requirements. The document states that all reporting should be made through the electronic format called EDIEL, the standard format for information exchange within the energy sector. Chapter 7 of the document summarizes the regulations for reporting of measurements made for single connection points within each grid owners network. Chap. 7, 2§ states that all measurements made for a specific connection point connecting two, or more, different grids to each other should be reported and shared between all grid owners involved in the connection. Chap. 7, 3§ states that all measurements for input to a grid by production units with a capacity larger than 1 MW should be reported to Svk, while chap. 7, 4§ provides the guidelines for reporting of electricity output from a grid. For electricity consumption within a grid, no reporting is required to Svk for specific connection points (Energimarknadsinspektionen 2016). Chapter 8 of the document further presents the regulations for reporting of collected hourly measurements made for a grid. Chap. 8, 2§ states that all collected measurements for connection points connecting two or more grids should be reported to Svk (Energimarknadsinspektionen 2016).

## 2.3 National data hub

In 2014, an investigation was conducted by Ei regarding the future handling of data on the Swedish electricity market. The results of this gave way to the development and future implementation of a national data hub for all actors on the Swedish electricity market. The purpose of the hub is to collect information for each connection point in the power grid. All actors are involved based on the same terms and the hub simplifies the contact, communication and information sharing among different actors. The development project was initiated in the end of 2016 and is to be finalized and implemented by the end of 2020. To the hub all information regarding connection points between grids is to be reported ([B]Svenska kraftnät 2016; [C]Svenska kraftnät 2016).

## 2.4 The Swedish power grid

The Swedish national grid, owned and operated by the TSO, consists of power lines of 400 kV and 220 kV as well as 16 international connections to surrounding countries. The national grid incorporates 15 000 km of power lines and many transformers. Connected directly to the national grid are the network customers; regional grids and large scale electricity producers ([A]Svenska kraftnät 2016). There are several types of transformers, one of them being phase-shifting transformers. Phase-shifting transformers have the advantage of being able to control the flow of active power through a power line. This can be beneficial in a highly interconnected network as it eases flow prediction (Siemens 2017).

Regional grids consist of power lines of 40 - 130 kV, with some exceptions of higher and lower voltages. Connected to the regional grids are some large scale consumers and producers, such as industries and electricity producers, as well as a several local grids. Similar to the national grid, the power lines of the regional grids are mainly overhead lines. In 2014, the power grid in Sweden included approximately 552 000 km of power lines, out of which local grids contributed with 90 % of the length. Local grids distribute electricity to small scale final consumers such as households, commercial buildings, smaller industries, and normally consist of power lines of 10 - 20 kV. A mix of overhead lines and cables constitutes the local grids ([A]Svenska kraftnät 2014).

The Swedish power grid consists of three different types of power lines; radial, interconnected and cross country lines. Radial lines are the simplest form and are only connected to a larger, interconnected grid in one end and consumption or production in the other. As they are only connected to a larger grid in one end, disturbance can affect the network to a large extent as the final location becomes isolated from the grid without the connection to the national grid by the radial power line. Interconnected lines are instead connected in both ends, increasing the robustness as there are alternative connections through which the electricity can be distributed in case of a defected line or congestion. The national grid is therefore constructed as a network of interconnected lines. Regional grids are furthermore connected to the national grid through several more interconnected lines, allowing for more alternative pathways as well as a secure, stable network. Radial lines are mostly found in smaller local grids, and from these to final consumers. The opposite of having a highly interconnected grid is reached when grids are sectioned, meaning that an interconnected power grid is changed into having a higher penetration of radial lines. Sectioning the grid decreases the grid stability, but increases the predictability of energy flows. Cross country lines are those connecting the Swedish power grid to that of surrounding countries, allowing for trade through import and export of electricity ([A]Svenska kraftnät 2014; [D]Svenska kraftnät 2016). An interconnected network can positively contribute to stability and security of supply as it offers alternative pathways for transmission of electricity. Meanwhile, it also presents complications for the management of the grid as it makes the energy flows in the grid less predictable (Nilsson & Guldbrand 2017).

## 2.5 National transit

Due to the structure of the power grid in Sweden, electricity is offered several alternative pathways as it is transported through the country, enabling a more secure and stable grid while simultaneously presenting challenges for the regulation and analysis of the flow. Electricity transported through the national grid which can pass over to underlying grids, normally regional grids, is referred to as national transit. Transit will occur to some extent as long as there are alternative pathways available. This causes additional loads for regional grid owners. Furthermore, depending on the state of the surrounding grid and whether there are international connections nearby resulting in import and export, the point of entry for the electrical power to a regional grid may differ. Due to this effect it is difficult to estimate the volume of capacity required for each connection point and regional grid owners may have to oversize the maximum capacity for several connection points. Today, Svk can compensate regional grid owners with difficulties establishing a suitable level of capacity per connection point due to large volume of national transit (Nilsson & Guldbrand 2017).

## 2.6 National grid connection tariffs

To cover costs for maintenance, operation and expansion of the national grid, a tariff has to be paid by those connected to the national grid. This tariff consists of two parts where the first is a capacity charge, and the second is a usage fee. In addition to these, users must also pay an excess capacity fee when exceeding the maximum capacity allowed according to their subscription. The revenues collected through the capacity charge are used to develop, strengthen and expand the national grid while the energy usage fee is used to cover losses in the grid ([A]Svenska kraftnät 2016).

The capacity charge is a fixed monthly fee revised annually that is based on the network customers' supply or consumption subscription in each point. This fee covers operation, maintenance, depreciation and capital costs associated with the national grid. The capacity charge rates changes linearly with the latitude of the connection point. The price of electricity supply is lower in southern Sweden and higher in the north. The opposite relation applies for electricity consumption, with lower prices in the north, and higher prices in the south where the electricity consumption is high ([D]Svenska kraftnät 2016).

The usage fee varies with the energy flow in each point. It covers the transmission losses in the national grid caused by the energy flow through the connection point. Depending on the geographic location of the connection point, a marginal loss coefficient is calculated. It is based on the losses created due to input and output in the specified point. The loss coefficient is derived from network simulations and calculations. It describes how the total amount of losses in the grid is affected by input or output in a connection point during normal operating conditions. For coefficients with a positive value, the grid losses increase with output and decrease with input, while the opposite happens for negative loss coefficients ([E]Svenska kraftnät 2016). This, multiplied with the energy flow and Svk's electricity loss price gives the usage fee. If the supply or consumption in a connection point decreases the transmission losses in the grid, it results in a reduction of the usage fee ([A]Svenska kraftnät 2016). Today, the electricity loss price used in the usage fee is constant throughout the year and defined in advance ([F]Svenska kraftnät 2016).

For capacity exceeding the allowance within the subscription, temporary capacity can be applied for at least one hour beforehand and for a period of seven days. Temporary capacity is charged 1/200 of the annual capacity charge per week and kW, as well as an additional charge of 1/500 of the annual capacity charge per used kWh ([B]Svenska kraftnät 2017). Based on recommendations by Svk, a temporary capacity charge subscription is feasible for capacity volumes reached less than 500 hours per year, equal to less than 5.7 % of the time. Peaks only occurring less than 500 hours per year are therefore, according to this recommendation, not feasible to include in the fixed monthly capacity charge (Nilsson & Guldbrand 2017).

In addition to the normal subscription fee, and temporary capacity payments, an excess capacity fee is charged when the maximum capacity allowance is exceeded for one connection point without a temporary capacity. The fee is equal to 1/500 of the annual capacity charge for the exceeded capacity on an hourly basis. After three hours, the fee increases to 1/50 of the annual capacity charge. Exceptions are made when the excess capacity occurs as a result of a fault in Svk's power lines ([B]Svenska kraftnät 2017).

## 2.7 Connection point joint subscription

The current model for economic compensation, called connection point joint subscription, can be described as two, or more, connection points which are joint in a shared subscription and therefore regarded as one single connection point when applying for a maximum capacity allowance. It is an exception to the normal grid connection tariff. The maximum capacity is what is considered when deciding a level for the capacity charge, which makes this a cheaper alternative than having separate connection point subscriptions. When applicable for a joint subscription, the owner of the regional grid notifies the assumed maximum capacity required in each one of the included connection points, based on which an overall maximum capacity for all connection points is calculated. The owner pays based on the capacity reported for each connection point as separate points, due to the fact that these connection points may have different connection tariffs as the tariff is based on location. However, as the grid is managed, no additional cost is added to the tariff when the maximum capacity for an individual point is exceeded as long as the total maximum capacity of the joint connection points is not exceeded as well. Only in the latter case is an additional cost charged (Nilsson & Guldbrand 2017).

Svk can accept a joint subscription application when a regional grid is subject to a large volume of transit. Transit, as defined by the user agreement for usage of the national grid, refers to the flow of energy entering a regional grid, later re-entering the national grid. The owner of the regional grid initially applies for a joint subscription for two, or more, connection points after which Svk decides to decline or accept the subscription. The decision is made based on historical input and output data from the concerned connection points ([B]Svenska kraftnät 2017). The decision to accept a request for a joint subscription is based on the size of the transit in relation to a given limit. If the transit for the area exceeds a given limit, the joint subscription is accepted. Two different type of effects developed as a result of transit are considered. The first is the increase in required output from the national grid in combination with a required input subscription, both as a result of national transit. The second effect considers the insecurity and variations in capacity requirements for each individual connection point as the output for different points differ depending on uncontrollable variables in the surrounding, such as import and export to neighboring countries, as well as national production in other parts of the grid ([B]Svenska kraftnät 2014).

To determine the effect of transit on regional grids, calculations are made for the capacity required for each connection point in the 95th percentile for historical input and output data. The capacity for each connection point involved in the application for a joint subscription is summarized for each hour and the total capacity required for all connection points in the 95th percentile is calculated. Then, the capacity in the 95th percentile for each connection point is summarized and divided by that for the entire joint subscription to give the ratio between what is considered the capacity exchange and the actual capacity requirement. If the capacity exchange in relation to the actual capacity requirement is larger than a stated limit, a joint subscription can be accepted ([B]Svenska kraftnät 2014). There are currently seven joint subscriptions spread out in Sweden.

## 2.8 International transit in the European Union

Transit does not only occur from the national grid to underlying grids within a country, but also across borders. As electricity is imported and exported internationally, several connections to international grids exist. Across these connections, international transit can occur. Similar to the national transit, this results in higher loads and losses and therefore a cost for the country allowing for transit through its grid. Furthermore, in order to enable a large capacity for transit, national transmission networks may require further grid development, increasing the related costs further (European Commission 2010).

In order to coordinate and enable for cooperation between the TSOs of national grids, the European Network of Transmission System Operators for Electricity, *ENTSO-E*, was established in 2009 by the EU. ENTSO-E represents 41 TSOs across 34 countries with the purpose of further enabling a liberalized and open electricity market in the EU. One of the areas of responsibility for the ENTSO-E is the compensation for international transit ([A]ENTSO-E 2015). Inter TSO Compensation, *ITC*, is an EU regulation designed to compensate TSOs for making infrastructure available as well as losses in the national grid due to cross-border transmissions. The main principle is that TSOs pay for the flow they cause through other countries' grids, and should be compensated for flows through their grids caused by others. In the ITC regulation transmission is defined as the lower of the absolute values for import and export, normally on an hourly basis. The model contains compensation and contribution for all member TSOs based on two aspects; required development of infrastructure and transmission losses (European Commission 2010).

Transmission loss calculations are split into contribution and compensation. The amount of losses is determined by comparing the amount of losses in the system to the estimated amount of losses without cross-border transmission. This multiplied with the loss electricity price gives the compensation value as shown in Equation 1. The contribution is calculated using Equation 2 in which the net flow price is multiplied with the sum of net export and net import of the

TSO. The net flow price, shown in Equation 3, is defined as the sum of compensation for all TSOs divided by the sum of net export and net import for all TSOs. Net import flows, *NIF*, and net export flows, *NEF*, are defined as in Equations 4 and 5 (Lassource 2014).

$$Compensation\ value = Transit\ losses * Loss\ electricity\ price \qquad \text{[Equation 1]}$$

$$Contribution = Net\ flow\ price * \sum(NIF + NEF) \qquad \text{[Equation 2]}$$

$$Net\ flow\ price = \frac{\sum_{ITC} Compensation}{\sum_{ITC} \sum[NIF+NEF]} \qquad \text{[Equation 3]}$$

$$NIF = \max(0;\ \sum Import - \sum Export) \qquad \text{[Equation 4]}$$

$$NEF = \max(0;\ \sum Export - \sum Import) \qquad \text{[Equation 5]}$$

The compensation for infrastructure development consists of two parts where the main component depends on funds available for compensation times the amount of transit, $T_{Country}$, through the country compared to the sum of transit, *T*, through all participating countries, as shown in Equation 6. The other part considers the vertical load, *L*, and monthly transmission distribution in the grid, but this part is weighted considerably lower. It is described in Equation 7 (Lassource 2014).

$$Compensation_{Transit\ share} = \frac{\sum T_{Country}}{\sum_{ITC} T} \qquad \text{[Equation 6]}$$

$$Compensation_{Load} = \frac{\frac{\left[\sum T_{Country}\right]^2}{\sum T_{Country} + \frac{m}{12} L_{Country}}}{\sum_{ITC} \frac{[\sum T]^2}{\sum T + \frac{m}{12} L}} \qquad \text{[Equation 7]}$$

The losses caused by international transit in member countries are calculated and presented in September the consecutive year. The published report then presents the allocation of compensation among the countries. Through its stable and secure grid, Sweden usually contributes with available capacity for international transit and has therefore received compensation the latest years. Compared to other member countries, the compensation given to Sweden is relatively high (ENTSO-E 2016; [B]ENTSO-E 2015).

## 2.9 Electricity market structures in Europe

This section describes the power systems for countries with similar conditions as Sweden and closely linked to the Swedish market, as well as some other electricity systems in Europe.

### 2.9.1 Denmark

The long range transmission grid in Denmark is owned by the TSO, Energinet, and consists of 400 kV lines. The regional transmission grid operates at 132 and 150 kV and is also owned and operated by the TSO. The last stage in the distribution system, the one to the end users, is owned and operated by local grid owners ([A]Energinet 2014). The eastern Danish electricity system is synchronized with the Nordic Power system, while the western part is synchronized with the continental European system ([B]Energinet 2014). Currently there is no model for compensation of national transit that is related to their national grid connection tariff (Buhr Broge 2017).

### 2.9.2 Norway

All high voltage power lines in Norway are owned and operated by the TSO, Statnett. They operate at the voltages 420, 300 and 120 kV. Distribution system operators, *DSO*, are responsible for transferring electricity from Statnett's grid to the end users. This is performed at a lower voltage (Statnett 2013). The tariff levels are different for consumption and production. The production tariff is based on two factors. The first one is the annual production volume, and the second the maximum production level. Electricity consumption is charged based on the maximum consumption (Statnett 2016). The Norwegian TSO does not have problems with extensive transit through regional grids, and there is no model for compensation for transit in place as of today (Ballestad 2017).

### 2.9.3 Finland

The Finnish power system is part of the synchronized Nordic power system. In addition to the Nordic countries, there are cross-border connections to Russia and Estonia. The TSO in Finland is Fingrid, which operate the 400, 220 and 110 kV lines. Distribution grids operate at voltages between 0.4 and 110 kV, and are responsible for transferring electricity to end users (Fingrid 2017). There is no model in place which compensates for national transit, as there are no problems related to extensive transit through regional grids. Regional grids are only used for transit when there are disturbances on the national grid lines (Sederlund 2017).

### 2.9.4 The Baltic States

The Baltic States include Estonia, Latvia and Lithuania, all previously members of the former Soviet Union, leaving them with an electricity grid and market structure unlike any other studied area. The Baltic States are part of the EU, however, the transmission system is part of the Integrated Power System/Unified Power System, *IPS/UPS*, owned and operated by Russia. Furthermore, the electricity market of the Baltic States is coupled with that of the Nordic countries, Nord Pool. The power grid in the Baltic States includes high-voltage lines of 110 kV and higher, operated by national TSOs (Bompard et al. 2017).

### 2.9.5 The Netherlands

The Dutch power grid is owned and operated by the national TSO, TenneT, managing all high-voltage power lines of 110 kV or higher. The TSO also supplies electricity directly to large scale consumers, such as industries. Connected to the grid are also large scale electricity producers, and the local distribution grids ([A]TenneT 2017). The grid is therefore divided into high-voltage transmission lines and low-voltage distribution lines, where what in Sweden is referred to as regional grids, are included in the high-voltage transmission grid, owned and operated by the national TSO.

### 2.9.6 Germany

The German national grid is split between four TSOs; 50Hertz, TenneT, Amprion and TransnetBW. TenneT owns and operates the power grid in the western part of the country with power lines of 110 kV and higher ([B]TenneT 2017). 50Hertz owns and operates the grid in the northern and central part of the country with power lines of 150 kV and higher (50Hertz 2017). Amprion owns and operates the grid in the eastern part of the country with power lines of 220 kV and 380 kV (Amprion 2017). Finally, TransnetBW owns and operates the grid in one smaller region in the southwestern part of the country. Their grid consists of power lines of 220 kV and 380 kV (TransnetBW 2017).

# 3 Current state of the art

In this part, the current compensation state is analyzed with respect to the current compensation model, and the areas subject to the compensation. The joint subscriptions in place today are studied in order to determine the reason for, and size of, the compensation today, as well as the different structures of regional grids receiving compensation. The section further presents the results from the interviews with representatives from Svk and regional grid owners currently operating a grid with connection points involved in a joint subscription.

## 3.1 Method of analysis

In order to assess possible future models, the current model was analyzed using input and output capacity measurements for each connection point involved in a joint subscription during the year of 2016. All data is provided by Svk and based on their actual measurements of flows on the national grid, as well as the actual billing of the regional grid owners. As the data is classified, only tendencies are published in this report. Measurements are available for input and output on an hourly basis. The fixed monthly subscription capacity is given for each connection point within the joint subscription, as well as for the joint subscription as a total.

Firstly, the structure of the joint subscription is investigated. This is made through an analysis of the geographic location of each connection point. The nearby area is also analyzed with regards to supply and demand of electricity which may affect the connection point capacities. Furthermore, the relation between the maximum capacity per connection point set in the fixed subscription and the actual capacity requirement during the year is investigated. The analysis is made through a comparison of the capacities applied for during 2016 and the actual measurements from the same year. This describes the nature of the joint subscription and could show if there is a possibility for extensive national transit through the connection points. The results further presents occasions of excess capacity, above the limit for maximum capacity of the joint subscription. The calculations are made using Equation 8 where the capacity for each connection point, $i$, is summarized and compared to the capacity allowed according to the joint subscription, $P_{JS}$, presenting the difference, $\Delta$. If the equation returns a positive value, the subscription is exceeded. In addition to the quantitative analysis, a qualitative analysis of the historical applications made by the regional grid owners is made in order to establish what reasons the owners have to apply for such a subscription, indicating what compensation they consider.

$$\Delta = \sum_{i=1}^{n}(P_i) - P_{JS} \qquad \text{[Equation 8]}$$

The current connection point joint subscriptions were studied to find how much of a discount is currently given as a compensation for transit. This was performed through estimating what capacity charges the connection points in these subscriptions would have if they had normal subscriptions, meaning one subscription per connection point. An approximate capacity charge level was found through analyzing the maximum hourly energy flow during the year of 2016, as well as the 95th and 98th percentile for each connection point. An approximate subscription cost of separate subscriptions for each point currently involved in a joint subscription was calculated using the assumption that a request is made for a temporary capacity charge for capacity levels occurring less than 500 hours per year in accordance with the previously mentioned recommendation from Svk. This equals a percentage of approximately 5.7 %. Therefore, the 95th percentile of power input and output data has been used as an approximate maximum capacity required for the subscription of a connection point.

Equation 9 shows the calculation method of the total require capacity applied for if the area would have separate subscriptions for each connection point, referred to as $P_{subscriptions}$. For each connection point, the required capacity in the 95th percentile is calculated, $P_{i,95}$ where i represents a connection point. The required capacities in the 95th percentile for all connection points are then summarized to give $P_{subscriptions}$. In order to establish the total price of all separate subscriptions, $C_{subscriptions}$, the capacity in each connection point in the 95th is multiplied by the capacity charge in each respective connection point, $c_i$, according to Equation 10.

$$P_{subscriptions} = P_{i,95} + P_{2,95} + \cdots + P_{n,95} \quad \text{[Equation 9]}$$

$$C_{subscriptions} = P_{1,95} * c_1 + P_{2,95} * c_2 + \cdots + P_{n,95} * c_n \quad \text{[Equation 10]}$$

Furthermore, the amount of temporary capacity payments for each joint subscription during the year of 2016 is analyzed, as well as the excess usage fee. The total price paid for temporary capacity is related to the total fixed capacity charge for the entire year and the amount of temporary capacity is in this way given as a share of the total capacity in the fixed subscription. The usage fee is not included in these calculations as compensation today is given only with regards to the capacity charge. The excess capacity is evaluated in the same manner. The total cost of excess capacity per joint subscription for the entire year is divided by the total price of the fixed subscription price, excluding the usage fee. When establishing the theoretical price subscriptions used if joint subscriptions did not exist, it is assumed that the same share of temporary capacity and excess in capacity is required as the grid is still subject to the same unpredictability.

The analysis is further developed through the collection of notions and opinions from representatives from Svk as well as from the regional grid owners currently operating with one or more joint subscriptions. Information from Svk is collected to establish what complications arise due to joint subscriptions, as well as for inspiration for areas of improvements and for formulation of basic assumptions for future models. Regional grid owners were contacted and asked to give their opinion on what added value the joint subscription created for them in order to establish an efficient method for including the customer desire in the model. Representatives of TSOs in other Nordic countries were also contacted to discuss if similar problems appear in their grids, and how they handle compensation for extensive transit through regional grids.

## 3.2 Analysis of current model

Interviews were conducted with five different employees at Svk, representing financial, market and grid analysis units. The overall opinion expressed during interviews is that some kind of compensation is desired. A model for compensation should incentivize the regional grid owners to develop their grid at the same pace as that of the national grid when it is beneficial from a socioeconomic perspective, compared to development of the national grid.

For the financial unit, an additional workload is created as a result of the joint subscriptions as they are not charged in the same manner as regular subscriptions. The joint subscriptions also include several connection points which require additional calculations to perform. A requirement for a new compensation model made by the financial unit is that the model should not reduce the level of predictability of capacity allocation as estimations of revenues for each year are required prior to the actual energy flows. Furthermore, a clearer framework on when compensation should be awarded is desired.

Simulations are made for the actual energy flows on the grid in order to evaluate the available capacity to create a model of the future required development of the national grid. The existence of joint subscriptions aggravate the analysis of such a model as it is difficult to predict where the actual flow of energy will occur for an area with a joint subscription. This area is allowed to redirect capacity as long as the total maximum capacity allowance of the joint subscription is not exceeded. The desired requirement of the new compensation model made by the grid analysis unit is that it indicates how the capacity and energy flow is managed by the regional grids in a clearer manner than today. Each connection point should be handled separately as it allows for other possible subscriptions than what is possible when a joint subscription is in place. The model should also be clear with regards to when and why compensation is rewarded, and should contribute to overall social welfare and sustainability.

To all companies that own and manage a regional grid currently involved in a joint subscription, a request was sent for opinions on what the experienced benefits are, both technical and financial. The replies show that the most distinguished benefit experienced is that of the technical management of the grid as they are not required to apply for temporary capacity on a regular basis. Several of the grids with a joint subscription today experience fluctuation in input and output for different connection points within their grid, depending on the activities on the surrounding national grid. Large volumes of import and export in nearby areas result in fluctuations in output as the available capacity is shifted from one area to another and therefore different connection points. Several international connections handle large volumes of both import and export. The impact for the owners of the grid is the uncertainty in allocation of input and output capacity as there is a large variation in capacity required depending on the surrounding environment, and specifically with regards to the import and export in nearby areas. The variation results in difficulties in establishing an efficient level for the subscription capacity for individual connection points and frequent demand of excess capacity which are to be covered through temporary capacity allowances applied for each time the subscription is expected to be exceeded. The transit experienced by the interviewed regional grid owners is a form of internal transit where capacity is transferred from one connection point, through the regional grid, to an area which is located closer to another connection point through which it is desired that the capacity enters the grid. Another opinion presented by the regional grid owners is that the sectioning of the grids is not possible for most grids as it would decrease the security of supply. It is therefore unlikely that the regional grids covering large city regions would section their grid in the case of removal of the compensation.

### 3.2.1 Current joint subscriptions

There are a total of seven joint subscriptions in place in Sweden which hereafter are referred to as Subscription 1 - 7. Some of the subscriptions were found to handle areas where it is hard to predict from which connection point energy will flow, for example in bigger city regions where there are several proximate connection points. The results below present the structure of each joint subscription, as well as an estimation of the size of compensation. All temporary capacity accepted for 2016 is on a weekly basis, meaning the temporary subscription is valid for one week. All the grids with a joint subscription applied for and were approved temporary capacity more than one week during 2016, with the exception of Subscription 3. The amount of temporary capacity payments compared to the total fixed cost is small for all subscriptions, never exceeding 0.8 % for any of the subscriptions.

Studies of historically submitted documents from the regional grid owners show that most of the joint subscriptions are based on the reasoning that nearby international electricity import and export affects which connection point the capacity enters through, and additional load is created due to import and export. Furthermore, the existence of power lines within a regional grid, parallel to those in the national grid creates transit through the regional grid as they offer an alternative pathway. These two are the main reasons for application for joint subscriptions historically. When examining the current joint subscriptions as described in Section 3.1, the cost change when removing the joint subscriptions as compared to the cost paid in 2016 is shown in Table 1. A positive value indicates an increase in costs if the joint subscription did not exist, while a negative value indicates that the costs would have been lower with individual subscriptions.

Table 1. The relative cost change for regional grid owners if current joint subscriptions were removed.

| Subscription | Cost change [%] |
|---|---|
| 1 | -13.1 |
| 2 | -10.2 |
| 3 | +4.7 |
| 4 | -1.2 |
| 5 | +31.1 |
| 6 | -10.6 |
| 7 | -23.6 |
| **Total** | **-3.1** |

*3.2.1.1 Subscription 1*

The first subscription involves two connection points which offer an alternative pathway between two power lines in the national grid. The joint subscription only includes output capacity from the national grid. However, input occurs at several hours of the year, presenting the possibility of national transit through the regional grid according to the definition of transit used in the user agreement. The total maximum capacity of the joint subscription was only exceeded less than 0.4 % of the time during 2016. The per connection point capacity allowance is rarely exceeded and the total capacity of the joint subscription is divided among the connection points based on actual capacity output.

*3.2.1.2 Subscription 2*

The second subscription involves four connection points located close to international connection points, resulting in both import and export in close by areas. Furthermore, the area can be defined as a big city region with a subscription involving both output as well as input. It is characterized by large consumption and negligible volumes of production, resulting in the possibility of national transit occurring through the regional grid. The total maximum capacity allowed for the joint subscription is divided between the four connection points with regards to the input and output. The per connection point capacity allowance was only exceeded 2 % of the time in 2016. The total maximum capacity of the joint subscription was only exceeded less than 0.2 % of the time which was covered by temporary capacity payments.

*3.2.1.3 Subscription 3*

The third subscription involves five connection points located in an area that can be described as a big city region characterized by large hourly output and no input. The region did not fulfill the stated requirements for a joint subscription for the included connection points as no transit per definition can occur when no electricity re-enters the national grid. The total maximum capacity allowed for the joint subscription is divided equally across the five connection points. However, historical data and calculations show that the actual output varies between the connection points. Two points continuously exceed their per connection point capacity allowance with 47 % and 12 % respectively, at least 5 % of the time. The total maximum capacity of the joint subscription was only exceeded less than 0.1 % of the time in 2016. For this subscription, no temporary capacity was accepted and the exceeded capacity was instead fined.

*3.2.1.4 Subscription 4*

The fourth subscription involves two connection points located in an area that can be defined as a big city region located close to an international connection offering both import and export capacity, resulting in an effect on the regional grid. The subscription only includes output capacity which is divided across the two connection points according to actual capacity output. The total maximum capacity of the joint subscription was only exceeded less than 3.5 % of the time in 2016. However, calculations show that the per connection point capacity allowance is exceeded approximately 5 % of the time, in both connection points. The excess in output was covered by temporary capacity payments, as well as a small share of excess fines.

*3.2.1.5 Subscription 5*

The fifth subscription involves three connection points that surround an area defined as a smaller city region. The region is dominated by electricity consumption, but it is possible that transit occurs in this area since all three points are connected to each other in a fairly interconnected regional grid. However, within the regional grid there are several electricity producing units increasing the level of difficulty to determine the transit occurring. In addition to this, during 2016 no electricity was transferred to the national grid from any of the three connection points meaning the points do not fulfill the requirements stated for a joint subscription as no transit can occur. The total capacity allowance for the subscription is exceeded 5 % of the year for which temporary capacity payments are made.

*3.2.1.6 Subscription 6*

The sixth subscription involves three connection points located close to several areas with prominent hydropower capacity and are therefore connected to electricity producing units. The subscription is characterized by large input capacity and a small share of output capacity. As both input and output occurs, there is a potential for transit in the area. The input capacity allowance is only exceeded less than 0.1 % of the time, however, the output capacity allowance is exceeded approximately 9 % of the time, which is paid through temporary capacity payments. The total maximum capacity of the joint subscription points is divided between the points and is related to the actual measured capacity requirement.

*3.2.1.7 Subscription 7*

The seventh subscription involves two connection points, located in different bidding areas. The points are located far from each other geographically, with a weak connection between them. This means that the basis for having a joint subscription is weak. However, as this connection crosses the border between two different bidding areas it can contribute with added value as congestion might occur during the transmission of electricity between the two areas. This indicates that transit might occur between the two connection points. The output from the national grid to the regional grid is only exceeded less than 0.1 % of the year, while the input to the national grid is exceeded more than 5 % of the year. The additional input is paid through temporary capacity payments. Both connection points in the joint subscription have electricity producing units directly connected which indicates that the excess in input might also occur as a result of large volumes of production in combination with decreased demand on the regional grid.

## 3.3 Conclusions of current situation

From the analysis of the current situation it has been discovered that few of the joint subscriptions have been granted due to transits through the regional grids. At least half of the subscriptions are instead used in areas where electricity input or output is hard to predict due to highly interconnected grids, and proximity of connection points. Variation in input and output in connection points can be a result of transit but is, as stated earlier, only one of the considered effects of transit. Variation can be caused in numerous ways, where transit is one but not the only explanation. This suggests that the current method for national transit compensation does not fulfil its purpose completely as it only considers one effect of transit, which is not the one defined in the user agreement. Therefore it is of importance to redefine transit in the user agreement if it is desired to keep using the current compensation model. A more accurate definition should include what can be described as internal transit as well. Internal transit in this case refers to electrical power entering a regional grid through a connection point located far from the area in which the electricity is consumed. The point of entry is based on the activities on the national grid.

Four of the seven joint subscriptions fed no electricity to the national grid in 2016, meaning no transit actually occurred as the definition of transit includes an energy flow from the regional, to the national, grid. The joint subscriptions described do not include all connection points within each related regional grid. This results in an insufficient analysis to determine if any transit occurs since there might be other connection points through which an energy flow occurs as a result of transit with input or output in one of the points included in the joint subscription. The described analysis in this section is therefore not sufficient to determine actual transit, but rather give an indication as to if transit could occur or not.

There are currently no calculation methods which can accurately estimate all effects from national transits, and the areas approved for joint subscriptions are assumed to be subject to transit based on the information in applications from the regional grid owners, as well as the structure of the grid and surrounding power lines. Most joint subscriptions were approved a long time ago and might have been subject to transit at the time of application. However, as demand has increased in several regions, leading to a decreased transmission capacity, transit might not occur today. Calculations are made with regards to variation in input and output, but not transit through regional grids. The transit is simulated through calculations of capacity requirement for each connection point in the 95th percentile, and the total capacity requirement for the connection points of interest in the 95th percentile. The capacity requirement for each connection point summarized is considered the capacity exchange occurring. The total capacity requirement is considered the actual required capacity for the grid. Assuming the total capacity requirement for all connection points is the actual required size is not fully accurate as transit always occurs and therefore already affects the measurements.

From an analysis of the total cost for each joint subscription during the year of 2016 in comparison to the theoretical payments required based on the capacity required for each subscription point, the conclusion is made that the compensation level today is negligible. This is a result of the low levels of exceeded capacity volumes and excess payments made. The total capacity allowance is rarely exceeded, for all joint subscriptions, indicating that the capacity requirement applied for is estimated to reach a higher level than what occurred in 2016. Due to the rarely exceeded capacity allowance, analysis shows that several of the today existing joint subscriptions pay a higher subscription fee than what would theoretically be required in the case of separate subscriptions for each connection point. The total cost change for all connection points if the joint subscriptions were replaced with separate subscriptions would theoretically be -3.1 %, meaning the monthly capacity charge payments would decrease overall for the grid owners.

An exemption from the general rule is for Subscription 3. In this area, the analysis shows that the available capacity on the grid is limited due to high demand. This subscription was therefore not granted any temporary additional capacity during 2016, but instead paid excess fines when the allowance was exceeded. If the joint subscription for this area would be removed, the total capacity required for all individual connection points would result in a larger total capacity than that of the joint subscription today, as demand in this area is high. The joint subscription in this area can therefore be assumed to constrain the regional grid rather than compensate for transit.

Another subscription which is an exemption from the general rule is Subscription 5. The owners of this grid would increase their costs if the joint subscription was removed. This can be explained mainly by the percentage of temporary capacity at approximately 5 %, the recommended share. Furthermore, the allocation of capacity between the connection points is different from that applied for. The capacity for the connection points with a higher monthly cost are used at a capacity larger than that applied for, while for cheaper connection point, a larger capacity is applied for than that actually utilized. This shift in capacity decreases the cost of their current subscription.

Based on the benefits presented by the interviewed regional grid owners, it is determined that the main effect experienced is internal transit where power enters the grid in one connection point, to be transmitted through their grid to an area located closer to a different connection point. The opinion expressed is that this effect is caused by the surrounding environment, the national grid, and should be considered a transit as the flow would have chosen a different pathway if the regional grid was sectioned. The regional grid is therefore believed to relieve the national grid as capacity is transmitted through it instead of on the national grid. The situation on the national grid further causes large variation in output capacity for the different connection points as the capacity is made available in different areas surrounding the regional grid and therefore enters the grid at different points depending on the state of the national grid at that instance. This effect causes difficulties for the operation of the regional grids as well as for the application for subscription capacity. It can therefore be argued that this effect is a more significant problem for the regional grids than that of the transit through their grids. The expressed opinion by regional grid owners is that the increase in security for operation and management is a higher valued compensation than an actual economic compensation.

The structure, ownership and operation of the Swedish power grid is unlike many of the neighboring countries, as the regional grids in Sweden are owned by companies other than the TSO. As stated in the literature review, the high-voltage power lines of 110 kV and above are commonly owned and operated by the national TSO, however, in the case of Sweden, only lines of voltages from 220 to 400 kV are managed and owned by Svk. This means a higher likelihood for national transits occurring through regional grids as these have a higher capacity in Sweden than in the other studied countries. The structure of the power grid ownership in some regions in Germany has been discovered to be similar to that in Sweden. This indicated that the same effects from transit may occur in these regions. However, no records have been found stating any form of compensation for such a national transit within these regions.

# 4 Alternative compensation models

In this section, a set of potential compensation models are developed and presented. All models are based on the basic assumptions presented below. The function of an economic compensation model is analyzed in order to establish important aspects and the purpose of economic compensation. Thereafter, three cases and a reference case are presented for which the technical compensation models are analyzed for the purpose of validating their applicability. Finally, the steps of a SWOT analysis are presented. This method is used in order to compare the models, using the same criteria. Results are presented in Section 5.

## 4.1 Basic assumptions

Based on the three rules of regulation; an objective point of view, fairness and non-discrimination, some basic assumptions are made which establish the basis for all models presented below. The assumptions are also made based on the technical structure of the grid, and are as follows;

- The cost of compensation is to be divided between all actors connected to the national grid
- Compensation is awarded without specifically punishing those affecting the system negatively
- Added value for security of supply can only be created across bidding areas and in connection to international connection points
- Separate subscriptions are to be used for each connection point
- A differentiation is made between national transit and variation in input and output

The first assumption is made based on the fact that the added value is given to all actors on the national grid and the cost should therefore be divided between everyone experiencing an increased level of security of supply, meaning everyone connected to the national grid. The second assumption is made based on negative effects that may occur when punishing actors affecting the national grid negatively, through production or consumption. Production and consumption are the two main activities on the grid, driving forces and necessary effects. They form the basic requirements of the grid and motivate its existence. All activities related to the connection to the grid could affect the load on the grid in a negative manner depending on the overall state and other activities within the national grid.

The third assumption is made based on where congestion might occur. As large volumes of electrical power is imported or exported through international connections, the power lines connected to the point of import or export are strained and congestion might occur which is decreased by an increased number of power lines connected to the point. The available capacity can be increased as a result of more power lines. The same effect exists between two different bidding areas as these are created based on where the demand and production occurs and congestion is common between bidding areas, resulting in different electricity prices during some hours and therefore a large transmission requirement. The added value described in this assumption is defined as the increase in available transmission capacity presented to the grid as more power lines present alternative routes for the electrical power. It is assumed that no such added value can be created by a regional grid within the same bidding area and not connected to an international connection point. This is due to the fact that within such an area the transmission capacity on the national grid is not limited and the contribution made by the regional grids is therefore negligible. In the case of a limited national grid, the regional grids would still not contribute with added value as large sections of the grid still are only covered by the national grid, therefore the limiting factor. This effect is shown in Figure 2 where the blue line represents the national grid. Red lines mark the limiting areas for transmission, showing that the maximum capacity for transmission from north to south or vice versa is still that of the national power line.

The fourth assumption is made based on the desire to simplify the operation and invoice of each connection point. Through separate subscriptions, all connection points operate with the same conditions and management for Svk is simplified since no separate handling is required. The fifth assumption is based on the different effects that may occur within the regional grids. Transit is defined according to the user agreement today stating that transit is a flow of energy entering the regional grid through one connection point only to later flow back to the national grid without being consumed within the regional grid. Variation is instead defined by large variation in input and output for a single connection point due to activity in the surrounding environment while the overall demand within the regional grid is kept rather constant.

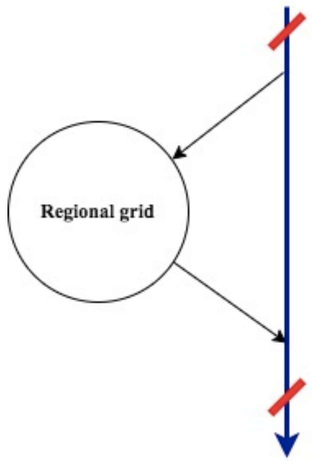


Figure 2. Limitation for transmission. The limiting areas are marked with a red line.

## 4.2 Economic compensation models

An economic compensation can be used as an economic instrument with the purpose to manage the behavior of market actors. In a chain of actions it is usually followed by a measure taken by the actor in a desirable direction. The reason for implementation of an economic instrument is to create incentive to act in a desired manner in order to reach a goal when the market fails to create such an incentive. The instrument can assist in correcting the failure (Naturvårdsverket 2012). The purpose can further be divided into three categories; directing, motivating and confirming actions. An optimum combination of these lead to clear goals and encourage desired behavior (SPP Pension & Försäkring 2016).

Economic compensation models are deployed in several sectors for varying purposes. An example is in the Swedish health care industry, where citizens can choose their healthcare provider, which in turn get economic compensation from public funds for providing their services. The compensation can either be based on the actual time spent providing the service or on the type of service provided. Regions where compensation is based on the type of service provided are motivating this with increased efficiency in resource allocation. This however increases the administrative costs for ensuring that time efficiency does not lead to decreased quality of performance. A drawback is that it is hard to assess an appropriate price for the service as it may vary from case to case and over time. A model based on the time spent performing the services creates an incentive for performing the service well, and gives opportunity to adjust the service to fit the citizen in need, but does not give incentives for efficient resource allocation (Sveriges Kommuner och Landsting 2009). Compensating based on the time spent performing the service can be interpreted as compensating based on the costs for the service provider, while basing the cost on the service performed is related to the benefit given to the citizen.

## 4.3 Model development

The development of the models is, as stated above, based on the assumptions presented, with the objective of compensating the regional grid owners for the high level of interconnections and the benefits created by it for the national grid. There are three new main approaches and reasons for compensation distinguished. The first approach is to compensate for the regional grid owners increased costs related to the use of their grid. The second approach is to compensate for the added value and benefits created for Svk through connecting the regional grid to the national grid. The third approach is to compensate for large variations in input and output in connection points between a regional grid and the national grid due to activities on the national grid.

For the first approach, each regional grid is defined as a system where all the connection points to the national grid are included. The system includes production and consumption within the grid, where the difference is regarded the export from the system. Connection points within the regional grid, and connections points between the regional grid and the national grid are included within the system boundary. Based on the third assumption presented in Section 4.1 the system boundary for the second approach of compensation is set around the connection point where an international connection is made or between bidding areas. Components included in the system for the second approach are only the national and regional power lines which are connected in the stated connection point. The connection to other power lines at a later stage in the grid is outside the system boundary. For the third approach, each regional grid is defined as a system where all the connection points to the national grid are included. Actual activities on the national grid, such as import and export, are outside the boundary of the system. The boundaries are visualized, by red dashed lines, for each separate system as the models are presented in Section 4.4 below.

The model development is divided into two parts, or sub models, where the first is the formation of a technical basis. The technical basis refers to the technical reason for compensation. This basis is used to measure the size of an effect and is later used to determine if compensation is to be awarded to a specific system, and used as an indication of the size of compensation, compared to other regional grids. The second part is an economic model for compensation, describing how capital can be allocated between different systems and presents alternatives as how to determine an appropriate level of compensation. For the second part, the model is limited to giving indications and recommendation of how to establish the size of compensation, however, it does not present any exact size of capital to be allocated for compensation as this is outside the scope of the project. The structure of the model development is presented in Figure 3 below. The two sub models together construct the overall main model, and theses are visualized below the main model in the figure. Data regarding the studied regional grid is fed to the model as input and information regarding the suggested compensation is given as output. The type of data fed to the system varies depending on the requested data for the technical base.

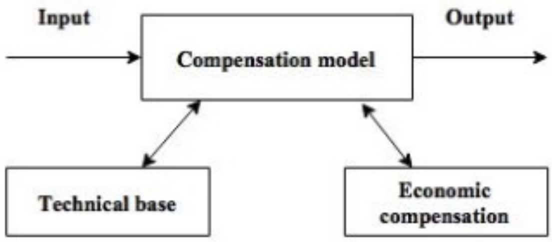


Figure 3. Structure of the model development and its related sub models

## 4.4 New basis for compensation

The technical basis for compensation models can vary. In the case of national transits through regional grids, three main new compensation bases have been identified as suitable. The first is the quantification of flows caused by transits. This method tries to capture how the flows, and therefore costs for regional grid owners, are affected by national transit in order to give them proper compensation that relates to increased costs. The second technical basis for compensation is the benefit the interconnected networks give to Svk. This model compensates for the service to the TSO, performed by the regional grid owners. It does not compensate for costs for regional grid owners but rather the costs avoided by the TSO. The third model analyzes the fluctuations in input and output for each connection point with the purpose of establishing whether the variation is caused by the national grid and surrounding environment or by the variation of load and demand within the regional grid itself. The model is based on compensation awarded to those highly affected by the fluctuating nature of the surrounding national grid resulting in difficulties anticipating the required capacity for each connection point within a regional grid. The last compensation basis can be seen as a variation of the joint subscriptions in place today. The models are further described in subsequent sections.

### 4.4.1 Compensation for actual transit

The first technical basis for compensation is the actual transit occurring through the regional grids. The used definition of transit in this case is that of electricity entering the regional grid from the national grid, only to later flow back to the national grid and therefore inducing losses and additional costs for the regional grid owners. This model calculates the flow of energy defined as transit and does not take variation in input and output into consideration. Figure 4 presents a basic model of a regional grid connected to a national power line, drawn in blue. Both power generation and consumption units are connected to the regional grid. The supply is visualized as two small wind turbines while the consumption is visualized by a factory representing a large scale consumer, and a local grid further connected to households representing small scale consumers. The transit is marked by the red arrow which shows the pathway of the transmitted electrical power.

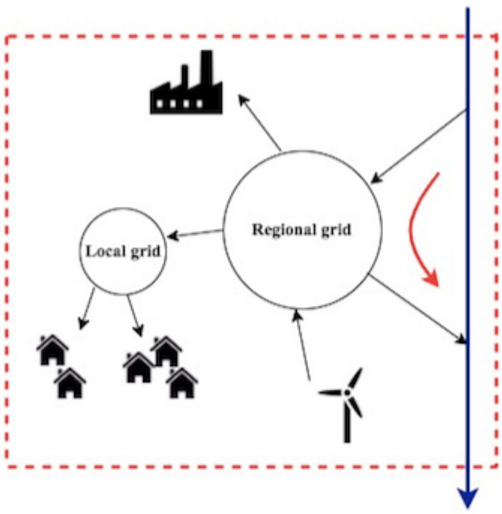


Figure 4. Actual transit through a regional grid. The transit is marked by the red arrow. The red dashed line indicates the system boundary.

#### *4.4.1.1 Calculation of actual transit*

With data from regional grids, a model can be developed which estimates the transits through each of the regional grids. The model requires data from the national grid connection points as well as the connection points within the regional grid that describe electricity generation and demand within the regional grid. In an ideal case, the losses within the regional grid should also be included in order to assess the total amount of transit through each regional grid. The transit would be calculated as the difference in input and output in relation to the actual demand on the regional grid, including its generation and losses. In these calculations the actual demand is calculated through studying each regional grid as a system, with the national grid connection points as the system boundary. The actual demand is equal to the import or export need from this system and is calculated through subtracting the consumption and losses from the production for each hour. The transit through the grid for each hour is then calculated through comparing the actual demand to the input and output from the national grid. The input to the model is hourly flow data from all connection points in a regional grid for a year, and the output of the model is an estimation of transit through the grid for the given year in MWh.

This basis requires extensive amounts of data collected from the regional grid owners in order to estimate the demand, generation and losses within each grid. Only with information of all parts is it possible to evaluate, in a fair and objective manner, the volume of transit through the grid. The information collected from the regional grid owners today does not include all posts needed in order to do the calculations and could therefore require data collection from regional grid owners.

#### *4.4.1.2 Economic models for compensation*

National transit through regional grids cause an increased cost for regional grid owners since it increases the energy flows through connection points and therefore the costs for grid connection. When applying for a maximum capacity for a connection point as a regional grid owner the maximum capacity can be affected by transit. Historical values of capacity can be assumed to be used as guidance as to future requirements, in combination with estimations of shifts in demand and supply. Therefore, as transit most likely occurred in previous years, it is included when assuming a maximum capacity required for upcoming years. Transit can also make the capacity exceed the maximum capacity level and therefore induce an excess fee. As for the usage fee, the regional grid owner pay for actual energy flow, including that existing due to transit. This compensation model compensates the grid owners for the additional costs due to transit through their grids.

The identified market failure used as basis for implementation of an economic instrument such as this compensation model can be described by external effects. The costs of transmission is shifted from the TSO to the regional grid owner when transit occurs and the true cost of transmission is therefore not paid by the TSO. The compensation is used to correct for the costs created for the grid owners by activities they are not able to control.

As a method for compensation, the increase in energy usage fee created due to transit could be repaid fully or partially creating a varying economic compensation. Transit occurs naturally based on the structure of the grid. Connection points are determined by the customers' connection to the national grid, and energy fed to and withdrawn from the grid due to demand and supply further affects energy flows. It is therefore reasonable to assume that only a portion of the cost of transit should be compensated for. Therefore, the model presented for compensation in this section compensates for a part of the costs related to the additional energy usage fee due to transit. In order to simplify the administrative process, the value of compensation per kWh could equal the cost per kWh for the usage fee in the affected connection point according to the national tariff, or a fraction of the same.

A fixed economic compensation method would require a fixed size of compensation capital which is to be allocated between the different regional grid owners based on their relative transit. The transit for each grid is to be estimated according to the previously described method. Based on this, the transit for a single regional grid could be compared to that of all other grids subject to national transit and the capital could be allocated accordingly. Regional grid owners receive a fraction of the compensation capital corresponding to their transit share relative to all regional grids subject to transit. In order to enable for this economic compensation method, the size of the initial capital has to be determined. This cost is later divided between all connection points in the country, as all users are assumed to gain from the increased capacity offered to the national grid due to national transit through regional grids.

### 4.4.2 Compensation for increased transmission capacity

An alternative model for compensation, not based on the actual transit, could be based on the benefit of an interconnected grid as it contributes with added value through increased transmission capacity. The compensation could therefore be based on the increased transmission capacity a regional grid contributes with through connecting to the national grid. The definition of added value through increased transmission capacity is defined in the basic assumptions and involved international connections and power lines across bidding areas. Figure 5 presents a model of such an international connection point where regional grid lines contribute with added value. The national power lines are visualized by blue lines while black lines indicate regional power lines. Red arrows show the pathway of the electrical power if no regional power lines were connected to the connection point. It is assumed that the regional power lines present alternative and additional pathways as capacity is limited on the national power lines.

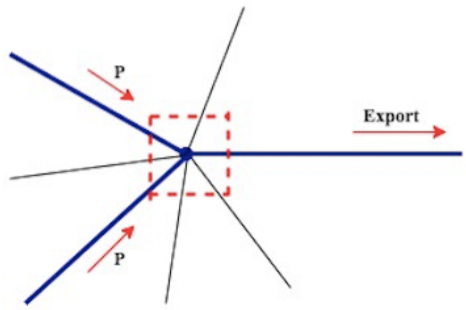


Figure 5. Increased transmission capacity created by regional power lines. Red arrows indicate the pathway for the electrical power if no regional power lines were connected. The red dashed line indicates the system boundary.

#### *4.4.2.1 Calculation of increased transmission capacity*

In order to estimate the increased transmission capacity provided by a regional grid, an analysis is conducted where power lines within a regional grid, connected to a point of interest, are disconnected one by one, creating an impact on the energy flows on the national power lines it is connected to. The impact is measured in terms of difference in power transmitted on the national power lines when the regional power line is connected or not. All power lines on a regional level connected to the studied connection point are analyzed in the same manner. The approach is used for each connection point in the national grid where regional power lines could contribute with added value, as defined in the basic assumptions. When there are more than one national power line connected to the concerned connection point, the sum of differences on all of the national power lines is calculated to estimate the total impact. Only positive contribution is considered and results are presented in terms of average increased transmission capacity in MW.

The calculation of added value and increased transmission capacity created by the regional power lines is performed in a similar manner as the calculations used for the loss coefficient, an established method already in use by Svk. In order to create a representative grid model, a combination of 72 system snapshots, called estimates, are used. These are taken from the third Wednesday of each month and the previous Sunday, at 3:30, 11:30 and 19:30, just as for the loss coefficient calculations and calculations for ITC. For regional power lines connected to a studied international connection point, calculations are performed for each of the 72 estimates. The values from these calculations are averaged over the number of estimates to create a single value for the benefit from each power line in MW transmission capacity added. The calculations can be performed annually with estimates representing the previous year.

#### *4.4.2.2 Economic models for compensation*

Economic compensation for this model is given on the basis that a benefit is created by the lines owned and operated by a regional grid owner. This benefit comes from increased transmission capacity for international transmission and transmission between bidding areas where congestion might occur. Svk are receiving compensation and revenues for providing both transmission between bidding areas and internationally and therefore it can be argued that compensation should be given to regional grids that help in providing the same service. International transit through Sweden gives Svk compensation from ITC funds, while congestion management within the country give revenues related to transmission across bidding areas.

The market failure identified as a basis for the model based on increased transmission capacity is the lack of incentive for regional grid owners to increase the level of interconnections within their grids. This should be encouraged when it is the most effective transmission solution from a socioeconomic perspective. Today, the regional grid owners may instead rely on development of the national grid. The construction of a highly interconnected regional grid with a large amount of power lines can result in lower demand of construction of several more national power lines. The economic instrument is in this case used to guide behavior towards constant, or increased, level of interconnection and development of more power lines within regional grids as they are compensated for the value created by power lines reducing the load on, and increasing the transmission capacity of, the national grid.

For the technical compensation model based on increased transmission capacity, an economic compensation with a varying basis is judged not suitable as the calculations are made on a yearly basis, in a similar manner as for the loss coefficient. The results from the calculations are given as differences in power transmitted through the national grid assuming the regional power line would not be connected, and given as an average for the entire year analysed. There is therefore no varying basis available to connect a varying economic compensation to.

Fixed compensation could be structured in a similar manner as for the compensation model considering actual transit through all regional grids. In this case a fixed compensation level is split between regional grid owners depending on how much their power lines contribute to the transmission capacity. The size of the fixed capital could be related to the revenues Svk receives for providing international transits, for example the compensation received in the ITC system. Today, ITC revenues for infrastructure are used to lower the capacity charge, and the ITC revenues for losses lower the energy usage fee. The revenues received in the national congestion management processes cannot directly be used for compensation as there are regulations stating what they can and cannot be used for ([A]Svenska kraftnät 2016). However, the size of the capital can be studied as a guideline for reasonable compensation levels.

Another possible basis is the estimated cost of building power lines within the national grid, with the same transmission capacity that the regional grids provide. This could be roughly calculated through studying all newly developed regional power lines, their building cost and transmission capacity and then calculate a rough average cost per MW transmission capacity. The payments of the compensation can either be divided over the months of the subsequent year, or be paid annually after calculations are performed.

### 4.4.3 Compensation for variation in input and output

Based on opinions presented by the regional grid owners currently operating connection points with a joint subscription one of the main effects experienced is large fluctuations in input or output. This can be caused by the activity on the national grid, due to nearby import, export or production. Even when the load within a regional grid is kept somewhat constant, output per connection point can differ depending on energy flows on the national grid, and its surrounding environment. A technical basis for compensation analyzed is therefore based on the variation in input and output for each connection point between a regional grid and the national grid. The variation for all connection points in a regional grid is compared to the variation in overall load within the grid. This model follows a similar approach as the one used today to determine whether an area is approved for a joint subscription. However, as opposed to the current model, this model includes all connection points within a regional grid to present a fair and more accurate result of the effects created. Furthermore, the model is based on the variation rather than the capacity requirement as it is difficult to determine the actual capacity requirement from the input and output due to the fact that transit is already included in these measurements and therefore affect the result. The model is visualized in Figure 6 by a regional grid with a constant load connected to the national power grid, which is marked in blue, in five connection points. The variation in input and output is visualized by the red arrows. In this figure it is assumed that the load of the grid is constant while the input and output in connection point 1 and 4 varies due to surrounding activity.

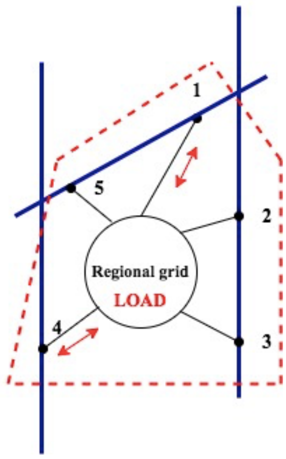


Figure 6. Variation in input and output through connection point 1 and 4. The variation is marked by red arrows and the constant demand is visualized as LOAD in red. The red dashed line indicates the system boundary.

*4.4.3.1. Calculation of variation in input and output*

For a regional grid, all connection points to the national grid are identified, and the hourly data for input and output is analyzed. For each connection point the standard deviation for the previous year's measurements is calculated and then summarized for all connection points. Furthermore, for every hour, the total input and output for all connection points is calculated. Based on these values a total standard deviation for the load of the grid is calculated. The summarized standard deviation for all connection points is divided by the total standard deviation for the load of the entire grid. This describes the relation between the variation in individual connection points to that of the grid's load. The calculation for the relative variation is made according to Equation 11, where $\sigma$ is the standard deviation.

$$Relative\ variation = \frac{\sum_{i=1}^{n} \sigma_i}{\sigma_{load}} \qquad \text{[Equation 11]}$$

*4.4.3.2 Economic models for compensation*

A fixed economic compensation model could distribute a compensation capital depending on the relative variation in each regional grid. Since some variation naturally occurs in all grids, a variation limit in percent could be set to exclude regional grids that are moderately affected by activity on the national grid. For a varying compensation base a fraction of the energy usage fee could be used. Depending on the variation in the grid a percentage of this fraction could be repaid. This means that the compensation would increase as the grid owners' costs do.

The identified market failure that the third compensation model aims to correct is related to external effects created due to the operation of the national grid. The surrounding environment will affect where input and output occurs within a regional grid and the environment is affected by the operation and management of the national grid. The model aims at compensating the grid owners for these external effects occurring due to the operation and management of the national grid.

## 4.5 Reformation of joint subscriptions

As a compliment to the new basis for compensation, the possibility of a reformation of the current model is analyzed. A suggestion of a reformed version of the current model is presented and evaluated. Furthermore, an analysis is conducted as to what the impact would be if the compensation for transit was removed completely. For these models no calculations or validation of applicability are made. They are rather used as a comparison to the new models previously presented.

### 4.5.1 Cost differentiated joint subscription

Activity on the national grid can affect where in regional grids input or output occurs even though the load is constant. This leads to regional grid owners applying for larger subscriptions than their actual demand as they need to allow for variations in distribution between connection points. The way this problem has been handled earlier, in the form of joint subscriptions, has been concluded to be subjective partially since not all subscriptions have been included in the system automatically. An alternative solution could be to have both a maximum capacity for each connection point, and a joint maximum capacity for each regional grid, where the cost of exceeding the individual limit is lower than that of exceeding the total capacity limit. The total capacity limit could be the sum of all individual points, or slightly lower if outputs and inputs are shifted in a way that does not increase the total output, but rather moves where it occurs. The compensation model is similar to that in use today, but with the difference that it has an individual subscription in each connection point and that it can be deployed for all regional grids rather than being an exception to the normal grid tariff. The purpose of this is to decrease the problems related to the current model, without inducing a calculation need.

### 4.5.2 Removal of compensation

As there are no requirements stated in the electricity act regarding compensation for national transit, removal of the compensation is regarded an option. As stated earlier, there is a desire within Svk to continue compensating the regional grid owners for extensive transit through regional grids. However, the option of removing the compensation completely is investigated in order to use the analysis as comparison to the other presented models and to establish effects that may occur due to the removal. Removal of compensation would mean that each connection point is involved in separate subscriptions as no other alterations are made to the current grid tariff. All other parts of the system, both physical and financial, are kept constant. As no economic instrument is deployed in this model, possible market failures are not corrected.

## 4.6 Applicability of technical compensation models

To validate the applicability of the presented technical models, they are adopted to four different cases, based on real power lines and connection points in the national grid, and regional grids connected to it. Three of the cases cover the aspect of international connections while the last is a grid located far from international connections. The fourth case is used as a reference case to study normal conditions. The models presented in Section 4.2, for which the needed data is available at Svk, are evaluated using the same cases to allow for comparison.

For the first technical basis of compensation, the actual transit, applicability validation can be made through calculation of the transit through each of the regional grids which own one of the connection points presented for the four different cases. For calculations for this model, the connection points for each case are used as basis to find which regional grid is to be analyzed. Currently there is a lack of information regarding the input and output for each connection point within a regional grid. There is not enough information collected regarding energy flows through connection points within regional grids to establish the actual transit occurring. Therefore, calculations cannot be made for this model with available data. However, it is still regarded as a future option, depending on what information will be collected as the national hub is established. The data could also be supplied annually by the regional grid owners. The model is therefore still used for comparison in Section 5.

For the second model, increased transmission capacity, the connection point presented for each case below is used for applicability validation. For each of the connection points it is analyzed how the transmitted power on the connected national power lines changes as one of the connected regional power lines is disconnected at a time. This symbolizes the effects created if one of these regional power lines were to be sectioned, decreasing the level of interconnections within the regional grid.

Validation of the applicability for the third model is performed in a similar manner as it would be for the first model. The presented connection point in each case is used as a reference for which regional grid to analyze. The data for input and output is then analyzed for each connection point within the regional grid in possession of the connection point in the case study.

#### 4.6.1 Case 1

The first case concerns an international connection where import and export may occur. The connection point of interest in this case is not included in a joint subscription today. Connected to the point are four national power lines and seven regional power lines. The regional grid which the connection point is a part of includes a total of three connection points to the national grid.

#### 4.6.2 Case 2

The second case concerns another international connection where import and export may occur. In this connection point, there is one national power line and six regional power lines. The area has an existing joint subscription today, including the connection point analyzed. The regional grid which the connection point is a part of includes a total of nine connection points to the national grid.

#### 4.6.3 Case 3

The third case concerns a third international connection where import and export may occur. In this area, there is an existing joint subscription today, including the connection point analyzed. There are three national power lines and two regional power lines connected to the point. The regional grid which the connection point is a part of includes a total of eleven connection points to the national grid.

#### 4.6.4 Reference case

A fourth case is created as a reference to the other cases. This case involves a connection point part of a regional grid which is not located in connection to, or nearby, any international connections. The effect from import and export can therefore be assumed to be small compared to the areas in the other cases. The grid connected to the point involves four connection points to the national grid.

### 4.7 SWOT analysis

The Strength, Weakness, Opportunity and Threat, *SWOT*, model was developed in the 1960's and is commonly used for business strategy development, product evaluation and strategic planning (Njoh 2017). The core purpose of the SWOT model is to identify a match between internal and external variables and it was originally developed to assess organizational strategies. The strengths and weaknesses of an organisation is compared to the threats and opportunities presented by its surrounding environment (Bell & Rochford 2016). In recent years, its field of application has increased and it is today to some extent used to evaluate areas such as energy technologies. It can be adapted to several cases and is usually presented in the form of a checklist for each category, or as a matrix (Njoh 2017). An example of such a matrix is presented in Figure 7. In this project, the SWOT model is used in order to analyze the presented compensation models in terms of product evaluation based on internal and external variables. The SWOT analysis further enables a comparison of the models as they are all subject to the same variables.

| | Positive | Negative |
|---|---|---|
| Internal factors | **Strengths** | **Weaknesses** |
| External factors | **Opportunities** | **Threats** |

Figure 7. Illustration of the components of a SWOT analysis presented in a matrix.

## 5 Results

In this section the results from the validation of applicability of the compensation models are presented, as well as the SWOT analysis for each model. The applicability validation is performed for the technical methods presented in order to establish the models' viability.

### 5.1 Applicability of technical compensation models

For each of the four cases, the new compensation models are tested to determine if the calculation methods can fulfil their intended purpose, and if the different cases are comparable to each other. As it has previously been established that there is a lack of information to calculate the actual transit, the first model is not presented in this validation of applicability. Calculations are made according to information presented in Section 4. Only the applicability of the developed technical bases is tested. Therefore, the reformation of the current model is not included in the case studies.

#### 5.1.1 Case 1

The results for Case 1 from the second model, increased transmission capacity, are shown in Table 2. Regional lines are referred to as R, and national lines N. Only positive contribution is regarded. It is clear that one regional line, R7, has a much greater contribution than the rest of the regional lines. The contribution is small as compared to the capacity of a national power line.

Table 2. Load change in MW on national lines, N, due to disconnection of regional lines, R, for Case 1.

| | N1 [MW] | N2 [MW] | N3 [MW] | N4 [MW] | N5 [MW] | Total [MW] |
|---|---|---|---|---|---|---|
| **R1** | 0.59 | 0.60 | 0.50 | 1.48 | 0.03 | 3.20 |
| **R2** | 0.07 | 0.02 | 0.05 | 0.07 | 0.01 | 0.22 |
| **R3** | 0.75 | 0.49 | 0.54 | 1.29 | 0.04 | 3.10 |
| **R4** | 0.41 | 0.33 | 0.27 | 0.64 | 0.01 | 1.66 |
| **R5** | 2.60 | 0.56 | 1.82 | 2.23 | 0.03 | 7.23 |
| **R6** | 0.54 | 0.49 | 0.39 | 1.21 | 0.04 | 2.66 |
| **R7** | 10.82 | 0.62 | 16.79 | 1.37 | 0.04 | 29.64 |
| **Total** | | | | | | 47.71 |

The results from the third model, variation in input and output, are shown in Table 3. The regional grid which the connection point is included in has a total of three connection points to the national grid. The results show the variation in input and output for each connection point summed, compared to the variation of the load of the grid. The difference in variation in output for each connection point is small compared to the variation in load for the entire grid.

Table 3. Relative variation in input and output compared to overall load variation in the grid for Case 1.

| | Input | Output |
|---|---|---|
| **Relative variation** | 5.4 % | 6.9 % |

#### 5.1.2 Case 2

The results for Case 2 from the second model, increased transmission capacity, are shown in Table 4. Regional lines are referred to as R, and national lines N. Only positive contribution is regarded. According to the results presented below, all six regional lines contribute with increased transmission capacity. The size of the contribution is comparable for all regional power lines and small as compared to the capacity of a national power line.

Table 4. Load change in MW on national lines, N, due to disconnection of regional lines, R, for Case 2.

| | N1 [MW] | Total [MW] |
|---|---|---|
| **R1** | 1.45 | 1.45 |
| **R2** | 5.34 | 5.34 |
| **R3** | 6.53 | 6.53 |
| **R4** | 1.93 | 1.93 |
| **R5** | 1.93 | 1.93 |
| **R6** | 7.24 | 7.24 |
| **Total** | | 24.42 |

The regional grid in which the connection point is included has a total of nine connection points. The results from the third model are shown in Table 5. The results show the variation in input and output for each connection point summed, compared to the variation of the load of the grid.

Table 5. Relative variation in input and output compared to overall load variation in the grid for Case 2.

| | Input | Output |
|---|---|---|
| **Relative variation** | 4.8 % | 30.9 % |

### 5.1.3 Case 3

The results for Case 3 from the second model, increased transmission capacity, are shown in Table 6. Regional lines are referred to as R, and national lines N. Only positive contribution is regarded.  Both regional power lines connected to the point contribute with increased capacity.

Table 6. Load change in MW on national lines, N, due to disconnection of regional lines, R, for Case 3.

| | N1 [MW] | N2 [MW] | N3 [MW] | Total [MW] |
|---|---|---|---|---|
| **R1** | 3.17 | 39.68 | 3.23 | 46.08 |
| **R2** | 3.42 | 57.49 | 3.32 | 64.22 |
| **Total** | | | | 110.30 |

The regional grid which the connection point is included in has a total of eleven connection points. The results from the third model, variation in input and output, are shown in Table 7. The results show the variation in input and output for each connection point summed, compared to the variation of the load of the grid.

Table 7. Relative variation in input and output compared to overall load variation in the grid for Case 3.

| | Input | Output |
|---|---|---|
| **Relative variation** | 41.1 % | 41.6 % |

### 5.1.4 Reference case

For the Reference case the second model is not applicable. This is due to the fact that the connection point and regional grid involved is not located in connection to an international connection or across two electricity bidding areas and therefore not adding any value to the transmission capacity, as defined in the basic assumptions. For the third model, based on variation in input and output, the area is applicable. The results of the analysis for this model are shown in Table 8. There are four connection points to the national grid involved in this regional grid. Only in one of the connection points is there power fed to the national grid which explains the 0.0 % in increase for variation in input. Even in this grid, which is not as affected by import and export as the previous cases, there is a higher variation of output in each connection point as compared to the variation within the grid.

Table 8. Relative variation in input and output compared to overall load variation in the grid for the Reference case.

| | **Input** | **Output** |
|---|---|---|
| **Relative variation** | 0.0 % | 13.0 % |

## 5.2 SWOT analysis

In this section the results from the SWOT analysis are presented. A SWOT analysis was conducted for each of the future alternatives presented in this project in order to enable for a comparison of the available options.

### 5.2.1 Technical basis 1 - Actual transit

In Figure 8 the result of the SWOT analysis for the model based on actual transit is presented.

| **Strengths** | **Weaknesses** |
|---|---|
| • The model is fair, handles transit within every regional grid<br>• Only model which would present the size of actual transit | • Not all transit creates added value for SvK and final consumers<br>• Measurements can be affected by other factors within the regional grid<br>• Type and basis for input measurements from regional grid owners may vary<br>• Measurement equipment used may differ, affecting results<br>• Gaps in measurements may exist<br>• Does not take variation in input and output into account |
| **Opportunities** | **Threats** |
| • The model may be supported further with the implementation of a national data hub<br>• The model may be made more efficient through the construction of a program that handles the existing data | • Depending on information collected by the future hub the model may not be viable within the near future |

Figure 8. The SWOT analysis of the model based on actual transit.

### 5.2.2 Technical basis 2 - Increased transmission capacity

In Figure 9 the result of the SWOT analysis for the model based on increased transmission capacity is presented.

| Strengths | Weaknesses |
| --- | --- |
| • Gives compensation for something actually contributing with added value<br>• The model is based on an existing method of calculation<br>• The model may be used with current systems and programs<br>• The model is currently applicable<br>• Encourage a high level of interconnections where required | • Not related to actual transit<br>• Not all regional grid owners are included<br>• It is difficult to estimate the added value economically<br>• Does not take variation into account |
| **Opportunities** | **Threats** |
| • The model can be made time efficient with the development of a script within existing programs | • Development and reconstruction of the grid changes the input to the model |

Figure 9. The SWOT analysis of the model based on increased transmission capacity.

### 5.2.3 Technical basis 3 - Variation in input and output

In Figure 10 the result of the SWOT analysis for the model based on variation in input and output is presented.

| Strengths | Weaknesses |
| --- | --- |
| • Variation is one of the main issues expressed by regional grid owners<br>• Easy to calculate<br>• The model is fair, handles variation within every regional grid<br>• The model may be used with current systems and programs<br>• The model is currently applicable | • Not related to actual transit<br>• Does not correlate with the added value created for Svk<br>• Variation is not only created due to activities on the national grid |
| **Opportunities** | **Threats** |
| • Introduction of more phase shifting transformers may decrease the variation in input and output | • Introduction of more renewable energy sources may increase the variation<br>• Increased amount of international connections may increase the variation |

Figure 10. The SWOT analysis of the model based on variation in input and output.

#### 5.2.4 Reformation of current model - Cost differentiated joint subscription

In Figure 11 the result of the SWOT analysis for the model based on a reformation of the current model into a cost differentiated joint subscription is presented.

| **Strengths** | **Weaknesses** |
|---|---|
| • Individual subscriptions per connection point but still presents flexibility for the regional grid owners<br>• Requires no additional calculations for Svk<br>• The model is fair, can include all regional grids | • Not related to actual transit<br>• Does not correlate with the added value created for Svk<br>• Would require a workload for the financial unit<br>• Would require new capacity reporting schemes for grid connection<br>• Not a compensation model but rather a reformation of the national grid tariff |
| **Opportunities** | **Threats** |
| | |

Figure 11. The SWOT analysis of the model based on a cost differentiated joint subscription.

#### 5.2.5 Reformation of current model - Removal of compensation

In Figure 12 the result of the SWOT analysis for the model based on the removal of the compensation is presented.

| **Strengths** | **Weaknesses** |
|---|---|
| • The easiest alternative<br>• No calculations are required<br>• No workload for financial unit | • No incentives given for actors<br>• Less market signals for when grid development is required<br>• No correction for unjust tariff for all users |
| **Opportunities** | **Threats** |
| • Possibility for innovative grid development to reduce effects from transit | • Regional grid owners may section their grids |

Figure 12. The SWOT analysis of the model based on the removal of compensation.

# 6 Discussion

In this section the results, conclusions and assumptions of previous sections are analyzed and discussed. The performed SWOT analyses, for which results are presented in Section 5, in combination with the case studies, are used as the main basis for the discussion presented below. The discussion is used as a basis for conclusions and remarks of the current model as well as new models and methods for compensation. It is also used to derive future recommendations and identify possible topics for future work.

## 6.1 Current model

The current model has been used without revision since 2012. From the analysis of the current model, it is clear that it does not compensate for all aspects of what it intends to compensate for. For example, its nature makes it unable to compensate for transit that is always occurring, since the calculations are based on measurements in which transit is included. The current method for analysis of transit occurring can be considered insufficient and not able to capture all effects from transit. This suggests that another analysis method is required to fully understand the effects transit cause in regional grids. Since the definition of transit used for approving joint subscriptions is that electricity has to flow from the national grid through the regional grid and then back to the national grid, many of the current joint subscriptions could be removed since this type of transit does not occur. It rather compensates for uncertainty in where input or output happens. This could be affected by activity on the national grid, such as proximity to extensive import or export, but could also be due to activities within the regional grid. If it is desired to keep the current compensation model, a change in the definition of national transit is required to reflect what the joint subscriptions actually compensate for.

The results show that the joint subscription compensation model in place today does not compensate the regional grid owners in the manner that was previously assumed, meaning for actual transit occurring. Since several of the joint subscriptions have a maximum capacity allowance larger than what would be necessary, the revenues to Svk from the subscriptions are higher than the theoretical minimum revenues based on separate subscriptions for each point involved in a joint subscription today. Therefore, it is not always a discount for regional grid owners as compared to having individual subscriptions. However, the level of compensation varies between the different subscriptions as they approach their maximum capacity a different amount of times during the year. It could also be assumed that the grid owners would like subscriptions with the same security margin, meaning that they still have capacity subscriptions that are larger than necessary to ensure always being within their subscription level. This assumption would show a larger discount with the joint subscriptions, but would not be a cost effective solution for the regional grid owners. A possible explanation for the unnecessarily high allowances could be that they are not revised by the regional grid owners annually, but merely based on what allowance they applied for during the previous year.

The economic compensation today is small for most grid owners with a joint subscription. Rather than economic compensation, the benefit experienced by the grid owners is the decrease in difficulty to manage the variations in input and output. The variation results in difficulty to anticipate the required capacity per connection point and subscriptions would have to be applied for at a level higher than actually required based on demand. The compensation experienced is therefore the simplified decision of total capacity required and easier grid operation. Therefore, even though the results show a small level of economic compensation, the opinions expressed by the regional grid owners is that the model is successful in compensating them for transit caused by Svk.

## 6.2 Basic assumptions

Dividing the cost of compensation between all actors connected to the national grid is motivated with everyone benefiting from a highly interconnected network. The cost of the compensation is then split in a similar manner as the capacity charge in the grid tariff. Actors that cause a large load on the national grid through for example electricity production in the northern parts or consumption in the southern parts of the country pay a higher capacity charge. Meanwhile, actors that consume electricity in areas with an abundance, or produce in an area with a power deficit, pay less. In the case of economic compensation with a fixed basis the collection of compensation capital could be divided between actors in the same manner as the division of the per MW capacity charge. Another approach would be to have only the actors causing extensive transit paying for the compensation. This could be done in several ways, and could be further analyzed in a future project. However, it is disregarded from in this project as no single actor should be punished for their connection to the power grid, as stated in the basic assumptions. Deciding to build models that reward desired behavior, rather than the opposite, was based on the assumption that receiving paybacks from a compensation system improves the trust in, and willingness to pay for, the system.

The nature of the electricity grid means that energy flows are always changing. This together with long term changes in demand and production can move the critical areas where transmission capacity is a limiting factor. Therefore the assumption that value is created across bidding areas and in connection with international connections, might have to be altered as the system changes. If the compensation is awarded based on the operation of the previous year the grid structure would only have to be revised when the compensation capital is divided between actors, meaning on a yearly basis. Therefore the required workload for the alteration is judged to be moderate.

The assumption that separate subscriptions are required for each connection point might limit the development of a new compensation model. It was assumed that separate subscriptions were needed to solve the problems related to grid planning. There is a possibility that other possible solutions were not identified because of this assumption. A future study may therefore involve an analysis of the development of a model based on other subscription models, an example being having one subscription for an entire regional grid. However, such an analysis has been disregarded from in this project as it is outside of the scope based on the basic assumptions made for a stable operation of the national grid.

## 6.3 Actual transit

A model based on actual transit has the advantage that all regional grid owners would be part of the compensation system. This could increase the experienced level of fairness of the grid tariff since everyone can receive paybacks from the system. The model is based on compensating the increased costs for regional grid owners due to transit. This is however not the same as the benefit for the TSO of the interconnected network since not all transit through regional grids occurs in areas where the transmission capacity is limited.

Calculating the actual transit in regional grids is a process that requires massive amounts of data from the regional grid owners. This is due to the fact that the energy flow related to transit is not explicitly measured, but rather has to be derived from other measurements. This means that the suggested method is suitable for comparing transits in different regional grids, but might not give the exact values when studying a single grid. This is due to the many simplifications used to enable calculations. Data used in calculations must be provided by the regional grid owners.

As presented in previous sections, the calculation method for this technical basis is judged not viable at current state. This is due to the lack of reported measurement data for the regional grids which would result in incomplete calculations and large margins of error for the result. There are measurements not required to report to Svk today which would be necessary for the calculation of actual transit. For example, there are no requirements on reporting data related to small scale electricity producers or large scale consumers in direct connection to a regional grid. One option would be to request the required information from the grid owners as they apply for compensation. It would also require separate and manual applications by each grid owner with a desire for compensation.

With the potential implementation of a hub, gathering information and data from all regional grid owners in the near future would improve the environment for the actual transit based compensation model. The hub could enable a more fair method for data gathering and constitute an objective basis for calculations as it removes the possibility for different data management regimes. The model could be further strengthened by the implementation of a national data hub since this could speed up calculations processes through automating them. It would also remove the need for manual submission of data. However, there are currently no guidelines for the requirement of data reporting for all connection points required for this model involved for the planned hub and it is therefore uncertain if the required information will be reported to such a hub within the near future. In addition to this, it is not yet established if the data can and should be used for this kind of calculations. This has to be further examined before deploying the model.

The proposed model based on actual transit would be based on data submitted by each regional grid owner and is therefore not absolutely coherent. This means that compensation based on the actual cost resulting from an increased usage fee would be subject to discussion as the model is required to be fair and objective. In addition to this, data points could be missing or incorrect. This is a disadvantage for a varying base for economic compensation. An advantage with a varying economic compensation model for this technical basis is that the compensation increases when the transit increases. It could also be used in such a way that the compensation would be given at the same time as the billing, rather than being based on the previous year. A fixed compensation model allocated based on the relation of transit among the grid owners could also be used as a compensation for actual transit. This would be a more robust model assuming that the fault in measurements is of similar magnitude in all regional grids. The grids with the larger share of transit would then receive a larger share of the compensation capital. This gives a fixed level of total compensation, increasing the predictability in compensation for both the TSO and the regional grid owners.

The implementation of this compensation as an economic instrument could aim to correct for the allocation of cost for transmission. As transit occurs in regional grids, the usage fee increases which means increased costs for regional grid owners due to activities which they are not able to control. When fully functioning, the proposed model would be able to correct for the market failure of allocation of costs. However, at current state the model lacks information required to correct for the presented market failure.

## 6.4 Increased transmission capacity

When basing a compensation model on the benefit of individual power lines, regional grid owners could find the system unfair as it only considers regions with transmission between national and international bidding areas. The second compensation model differs from the other two as it focuses on the value created for Svk, and all final consumers. The model focuses on rewarding regional grids that create value for Svk through strengthening the national grid, opposed to the other methods which mainly focus on the increased costs for regional grid owners.

The three studied cases have a different amount of connection points to the national grid. Case 1 only has three connection points while Case 2 and 3 have nine and eleven connection points respectively. The model is not applicable for the reference case. The results show that the total increase in transmission capacity created by a regional grid does not correlate to the amount of connection points to the national grid or to the amount of regional power lines connected in the studied point. This indicates that the surrounding environment and the potential congestion of a national power line can result in regional power lines being able to increase the transmission capacity. However, the total increased transmission capacity in all three cases is small compared to the capacity available on a national power line. The results show that the studied area and its surrounding environment heavily affect the contribution a regional power line may present and it is not possible to evaluate the contribution only based on the physical structure of the grid. The model presented in this project for increased transmission capacity based on the connection of regional power lines is successful in indicating the positive contribution made by the power lines.

A problem with this method is that studied areas have to be identified in advance, which means that the regions studied have to be revised manually when for example a new international connection is established. Since it is limited to areas close to an international connection or regional lines across bidding areas, this process should however not be extensive. It could possibly be automated. Basing the method on the same estimates as when calculating the loss coefficient for connection points gives it more credibility as this is a well-established method. However, it could be sufficient with fewer estimates as the rest of the grid would not affect the result as for loss coefficient calculations, but rather only the import or export close to the studied line. Fewer estimates could decrease the computation time as it decreases the number of calculations.

Another issue that may arise in this model is related to false positives. When using a method where all regional lines in an international connection point are disconnected individually, and then studying effects on the national grid lines, false positives may arise. This can for example occur when a production unit is connected through a radial line to an international connection point where export occurs. If the production unit is disconnected and the same export capacity is required, the result would be increased electrical power transferred on the national power lines although no transit normally occurs on the radial regional power line. Since estimates representing an entire year are used, the effect of temporary contribution and therefore false positives can be assumed to be limited, which is an argument for not decreasing the number of estimates.

Economic compensation for the benefit created by individual power lines could be performed in several ways. If the benefit is to be calculated in the proposed way, it would be revised annually which means that a fixed compensation model is more suitable as there is no varying variable that could be used as base for compensation which is associated with the benefit from power lines. A fixed model could either be based on a fixed capital distributed based on share of benefit, or through estimating a value for transmission capacity. The advantage of a fixed amount is that it means a predictable compensation cost for the TSO. In striving to reach a fair compensation model the other option could be more suitable. Deriving a value for the benefit of transmission capacity would be a more fair way of describing the cost associated with the power line as it is adapted to the actual costs the TSO would have without the regional line.

The objective of this compensation model as related to market failures is to correct for the lack of incentive for investment in development of regional power lines and the creation of a highly interconnected grid. Instead of constructing an additional national power line, the construction of several more regional power lines within the system may relieve the national power grid in a similar manner at a lower cost. It can therefore be assumed to be desired to have regional grids which are developed at the same pace as the national grid in order to avoid increased cost due to higher requirements on the national grid development. Development of the national grid should not be the preferred option to construction of new regional power lines when the regional grid is the limiting factor. This model presents incentives for grid owners connected to the connection points where cross country cables are connected. However, it does not send any signals to other players on the market. The level of interconnections within the regional grids not creating added value for Svk is not included in the model. The incentive is only created for the regional grid owners affecting the transmission capacity where it is regarded added value for Svk. It can further send signals to the market when increased capacity is required near international connections and new regional power lines may be constructed and connected to the related connection point.

## 6.5 Variation in input and output

The variation model attempts to compensate for the increased costs for regional grid owners due to activity on the national grid. It considers all connection points in a regional grid and compares the standard deviation for flow through the connection points individually to the standard deviation of the overall load. This could create a benefit for larger regional grids as the total variation is likely to decrease with increased number of connection points. Since more connection points mean more costs related to grid tariffs, and more possible output variation this could be deemed reasonable. If there would be a desire to increase compensation for small scale grids, the amount of connection points could be factored into calculations. The results from the four cases show that as the number of connection points to the national grid increases, so does the relative variation in individual connection points compared to variation in overall regional grid load.

A highly connected regional grid with several connection points to the national grid, such as the one presented in Case 3, in close connection to an international power line is subject to large variations in input and output. The variation could be explained by the import and export to neighboring countries but may also be a result of activities within the regional grid, such as varying production, or in the surrounding environment. The results further show that there are regional grids subject to large variation were incentives exist for compensation. The result from the four case studies could be used as a basis to establish a lower limit for when compensation is granted. Another option would be to grant every regional grid owner subject to such variations some compensation, but relate all grids to each other to create a fair division of the capital for compensation.

The first three cases all involve connection points in direct connection to cross country power lines in order to enable for validation of applicability of the second technical model. This results in the related areas being affected by import and export to a large extent which is one of the assumed reasons for increased variation in input and output for individual connection points in a regional grid. Therefore, the results of the third model are highly affected by the chosen areas for the case studies. The Reference case is used as a comparison. In this case the connection point of interest is located at a large distance from international connections and the assumption is therefore made that the area is less affected by import and export. The variation in output for all individual connection points related to that of the entire regional grid is 13.0 % which indicates that even though the grid is not highly affected by import and export, there are still variations in output in individual connection points. This is an important factor to take into account when establishing a limit for relative variation above which it is reasonable to award compensation. The alternative would be to give compensation to all regional grid owners based on the relative share of variation compared to each other.

The identified market failure that this compensation model may correct is external effects and the allocation of costs between actors. There are effects created on the regional grid due to the operation of the national grid which creates additional costs for the regional grid owners. Due to the unpredictable nature of the surrounding national grid there are difficulties in establishing the appropriate level of capacity requirement for individual connection points for the regional grid owners. Subscriptions may therefore have to be applied for with a higher capacity allowance than actually required, resulting in increased costs for the grid owners. This market failure is corrected through the implementation of the third model based on variation in input and output. The actual subscriptions would still require a higher capacity allowance than necessary, but the increase in cost would be compensated for during the following year. Situations where activity on the national grid, for example due to extensive international import, affect where output happens, are not handled by the actual transit and transmission capacity compensation models. For situations like that the third model is successful in giving compensation for increased costs due to activity on the national grid. It can however be argued that the regional grid owner operates in a market with a fluctuating nature, and should therefore not be compensated for the system acting in accordance with its nature. Having strong regional grids enable larger internal transits in regional grids, increasing the possibility for uncertainty in output. It also provides a greater security of supply and a more stable grid. It can therefore be considered that regional grid owners have to weigh these benefits against having increased uncertainty in output and therefore higher cost for national grid connections when planning the development of their grids.

It can be expected that the energy system in Sweden will incorporate a larger share of renewable energy sources within a near future. As several renewable energy sources are of a fluctuating nature, they will induce variating flows on the power grid as they are used for the electricity generation. This may further add to the variation in input and output in individual connection points. This effect is not controlled by the TSO and it can therefore be argued that it should not be compensated for by Svk. Separating the effects of renewable electricity production and that of transit due to import and export may be difficult in the future. The implementation of an increased share of renewable electricity production is therefore regarded as a future threat for the presented compensation model based on variation in input and output. Regional grid owners could choose to deploy phase-shifting transformers to a larger extent, thereby limiting the variation in their grids due to activity on the national grid. Grid owners can also affect the effect from activity on the national grid through their grid development strategies. For example they can choose to have an increased number of radial lines and a decreased number of interconnections, meaning less transmission capacity through their grids and thereby decreased variation in where input and output happen.

## 6.6 Cost differentiated joint subscription

Although the current model is capable of compensating for variations in input and output, it is lacking in objectivity since not all regional grids are included in the model automatically. Therefore, an alternative version of the current model was developed in the cost differentiated joint subscription model. It offers more predictability in where output occurs, and therefore decreases the problems related to grid development planning, yet keeps the flexibility for regional grid owners. If the grid owners have a buffer that allows for some additional capacity, problems could occur with everyday operation where outputs have to be predictable and known in order to balance the grid. If the system is deployed for all regional grids, the administrative problems caused by the current joint subscriptions being an exception are eliminated. In summary, the problems related to the current model are decreased with the improved model, but some of them remain. An example of a problem not removed by this model is the additional subscription required for all connection points for each regional grid. The predictability of where input and output will happen is increased but the financial aspects of billing are still complicated as compared to a model which only involves separate subscriptions. However, it has the advantage of billing being performed in the same way for all subscriptions. The model would also require constant monitoring as the subscription level might be exceeded at any time. Furthermore, the model would not present compensation for transit but rather be a reformation of the national grid tariff which handles variation in input and output.

## 6.7 Removal of compensation

Yet another option is the removal of all transit related compensation. This could result in a decrease in interconnections as the regional grid owners section their grids in order to decrease the transits through them. As the interconnections in the network decrease, the grid stability could decrease. As this is unwanted for both the national and regional grids, it is unlikely that the sectioning would be extensive. There are no regulations stating that compensation is required and every actor in possession of a grid for transmission and distribution is individually responsible for the stability of their respective grid. This means that Svk are not legally obligated to compensate for transits as the regional grid owners can avoid transits through other grid configurations. Apart from the grid configuration and sectioning it is important to take into account the signals created by an economic instrument such as a compensation model. When implemented in an efficient manner, the instrument should create incentives for positive behavior and send signals to the market actors when development or change in behavior is required. It should also motivate actors using the system through positive encouragement when desired behavior is presented as this should increase the experienced level of content and therefore willingness to pay. Therefore, completely removing the economic compensation model reduces the possibility of affecting grid development of regional grids.

Completely removing the compensation related to effects of transit would result in a less fair and just grid tariff. This is due to the fact that regional grid owners are greatly affected by activities on the national grid which they are not able to control. Additional costs are created due to these effects and not divided equally between all final consumers connected to the national grid.

## 6.8 Comparison & Evaluation of results

The nature of the compensation models differs greatly. If there is a desire to compensate for both transit through regional grids as well as variation due to activities on the national grid there is not a single method that considers both, but rather a combination would be needed. Furthermore, none of the models take into account both the increased costs for regional grid owners and the benefit created for Svk. Depending on what basis for compensation is of interest for Svk, different models may be used.

As previously mentioned, the EU encourages further development of cross-border transmission lines to increase the grid stability, and improve the conditions for consumers through leveling electricity prices. With an increased number of interconnections to other countries the possibility for further transit through the Swedish national grid is increased. This could affect the predictability of energy flows and increase variations in input and output in regional grids. This could also increase the amount of connection points in which it is possible that regional grids contribute with transmission capacity. These two effects should be considered when deciding on what type of compensation model is to be implemented.

The aim of the case studies was to evaluate the applicability of models, and provide deeper insight into their viability. As calculations were not possible for all compensation models, the evaluation of the models through the SWOT analyses is not based on equal terms. Although the first calculation model is not applicable today it could be a possible solution in the future. It could have been given an unfair disadvantage through not being included in the case studies, but as the data is currently unavailable it would have to be evaluated in a future study if it is to be implemented. Conclusions made in this project are based on the results from the validation of applicability through the case studies and SWOT analyses. It is judged that the two methods for comparison, cases studies and SWOT analyses, fulfil their intended purpose.

During the case studies, only data from 2016 is used for calculations. Only studying a single year induces an error since it is possible that the studied year is not representative for normal operation. For example, it could be a year with abnormal fluctuations in load distribution within the studied grids which would increase the variation in input and output. Since 2016 was a year with lower hydropower generation than an average year, it is possible that the electricity import and export could be affected as well as the transit levels through the country. As cases are only studied to assess applicability of models the studied data was deemed sufficient. Larger data sets could be assessed in future studies in order to determine compensation levels.

The proposed economic models are in many ways similar to those used in the healthcare industry. However, there are some major differences. When providing a healthcare service the customer experience and quality of performed work can have a great impact on the results. In compensation for national transit, the actual transit is not as affected by the compensation model chosen, with the exception of it steering future grid development. Because of this, some of the problems related to extensive administrative work related to quality measures in for example the healthcare sector, are not issues when deploying a compensation model for transit.

# 7 Conclusions & Recommendations

The compensation method with joint subscriptions, currently used for compensation of national transit, has been concluded to be insufficient and unable to fully fulfil its intended purpose according to the user agreement. This is mainly due to the fact that it only considers one effect of transit which is not the one defined in the user agreement. Three new compensation models, a reformation of the current model and the complete removal of compensation for transit are analyzed. The first new compensation model considers the actual transit through a regional grid and aims at compensating for the increased cost for regional grid owners associated with national transit. A second model is proposed in which the added value to Svk from regional grid power lines is evaluated. The third compensation model compensates for the increased cost regional grid owners get from activity on the national grid. This is investigated through studying the variation in input and output in individual connection points and comparing it to the variation in the total load of the grid.

Based on the validation of applicability it has been concluded that two of the new models are currently viable. The two models are the ones based on increased transmission capacity and variation in input and output. Depending on what reason for compensation is desired, different models may be implemented. The model based on increased transmission capacity compensates only specific regional grids which contribute with added value to Svk while the model based on variation in input and output can include every regional grid and compensate for the increased costs for the regional grid owners created due to activities on the national grid. The model based on actual transit is not viable with measurements currently collected and reported to Svk and it is not known whether the required information will be reported within the near future. This model is therefore judged as not viable today. Furthermore, the SWOT analysis for the model shows a large set of weaknesses.

The reformation of the current model into a cost differentiated joint subscription has shown to be an improvement of the existing model with an increased clarity as to when to compensate as all regional grids can be included in the model. It also reduces the difficulties in predicting where input and output may occur. However, it is concluded that it would require an additional workload for the financial unit as both individual connection point subscriptions as well as overall grid subscriptions would have to be handled. It can therefore be regarded as a reformation of the current grid tariff. The last model analyzed is the complete removal of a compensation model. It has been concluded that this is a viable option as several of the joint subscriptions in use today do not fulfil the requirements stated in the user agreement. Furthermore, removing the compensation would remove the workload required at Svk and is the easiest alternative. However, it would remove incentives given to the regional grid owners for positive behavior and fairness of operation and the interviews conducted at Svk show that there is a desire within the company to continue compensating for the effects of transit.

## 7.1 Future work

This project can be seen as an initial analysis of possible methods where the next step would be to estimate optimum compensation levels. Suggestions as to how this could be done are given to some extent when the models are presented, but no quantitative analysis is performed.

The analysis of the current situation and compensation model shows that one subscription, Subscription 5, is an exception from the general situation of the joint subscriptions. This area is characterized by high demand while the grid has a limited capacity required at its maximum during several occasions. The model for compensation of regional transit in place today is, for this geographical area, used as a restriction rather than a compensation for transit. There is no flow of electricity fed back to the national grid from this regional grid indicating that no transit, according to the original definition, can occur. However, if applying for separate subscriptions for each connection point in this grid the total capacity requirement for all connection point would exceed that of the current joint subscription. Allowing for separate subscriptions might not be possible due to limited capacity of the grid and the joint subscription in this area could therefore be necessary. Future analysis is recommended regarding this area and how to handle the subscription in a fair, objective and non-discriminating manner.

Future projects could further develop methods for compensation based on results presented in this project. None of the viable models presented quantifies the level of transit through the regional grids. In order to evaluate the level of transit an option could be to study the trends of input and output data. If input and output follow the same trends, it is possible that the regional grid is subject to national transit through the grid. Another alternative for future investigation could be the reformation of the current model into having separate subscriptions in each connection point and have a common buffer capacity for the entire grid. This would mean that they have a certain amount they can exceed their subscriptions without paying additional fines. This reformation of the current model would have to be evaluated further to understand the model's strengths and weaknesses. Finally, the alternative to keep the current model of joint subscription with an alteration of the definition in the user agreement has not been evaluated in this project as it is assumed that separate subscriptions should exist for each connection point. This method could also be an alternative for future compensation.

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