SWEDISH APPROACH FOR THE ASSESSMENT AND MONITORING OF THE SMART GRID DEVELOPMENT

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ABSTRACT

The Clean Energy Package aims to facilitate the energy transition. Electricity Directive (EU) 2019/944 (the Directive) as a part of the Clean Energy Package must be transposed into national law by the member states. The monitoring and the assessment of the development of a smart grid based on a limited set of indicators is introduced by the Directive as a task for the national regulatory authorities (NRAs). The Swedish NRA, the Swedish Energy Markets Inspectorate (Ei), has identified a set of indicators to be used for assessing and monitoring the smart grid development in Sweden. This article will describe the indicators that will be used for the assessment of the smart grid development in Sweden and its selection process. The aim of this article is to enhance the transparency and provide other member states with an overview over the Swedish approach.

INTRODUCTION

Power systems are undergoing fundamental changes driven by the energy transition. The energy transition is predominantly increased renewable energy sources (RES), more energy storage systems, innovative technical solutions, as well as a growing need for electrification and digitalisation. To cope with these changes the power system needs to be modernised and introduce flexibility to make it possible to match renewable generation with consumption. A commonly used term to describe this future power system is a smart grid. The term entails utilising new technology, new flexibility services and new market design.

To promote smart grids, Electricity Directive (EU) 2019/944 (the Directive), as a part of the Clean Energy Package, introduces a new task for the national regulatory authorities (NRAs) to monitor and assess the smart grid development. Furthermore, the NRAs will publish a national report every two years on the smart grid development and give recommendations. As a result, the Swedish Energy Markets Inspectorate (Ei) has adopted new national provisions where a set of indicators for assessing and monitoring the smart grid development is introduced in Sweden [1].

In the article *Smart Grid Indicators for the Swedish Regulatory Authority for the Implementation of the Clean Energy Package* Ei describes the overall objectives of the smart grid implementation, which aims towards energy transition (integration of RES), energy efficiency (asset management and efficient operation), resilient and reliable electricity grid [2].

SELECTION PROCESS

A literature review was conducted to identify indicators for the purpose of assessing and monitoring the development of a smart grid. Roughly 240 indicators were identified from the literature review. To analyse and narrow down the number of indicators, Ei used a set of evaluation criteria, see table 1. The list of indicators was analysed based on the criteria and with the help of a reference group consisting of grid companies, industry and branch organisations. [3]

Table 1 The criteria for the selection process of the indicators

Criteria	Description
Relevancy	The indicator must be relevant for the development of smart grids, either to the users or to society, for the cost of collecting the indicator to be justifiable.
Confidentiality	It must be possible to publish the indicator so that it can be used in the report that Ei must publish every two years in accordance with the Directive.
Measurability	It should be possible to measure or calculate the indicator.
Responsiveness	Shows to what degree a grid company can affect an indicator.
Technology neutrality	The indicator should describe a functionality of the grid and not a specific technical solution.
Availability	The grid companies must be able to gather the data.
Representativeness	It is preferable if the indicators can be compared between different grid companies.

Each identified indicator had to be relevant and be able to be published in order to be further analysed. Quantitative indicators were preferred over qualitative ones because qualitive indicators limit the potential for comparison between Sweden's grid companies.

Whether the grid companies could affect an indicator or not was not crucial when Ei chose which indicators to use. Since an indicator cannot alone show the smart grid development; a positive outcome for one indicator may result in a negative outcome for another indicator. For example, an increased use of flexibility can result in positive effects such as evening out the load, but it can also worsen some aspects of voltage quality. Voltage variations increase due to end-users that have weaker network strength being connected in/out more frequently. In addition, a grid company may be able to affect an indicator, but it might not result in the best solution for that grid. An example is the use of flexibility services indicator. In that case, the grid companies can increase the value by using more flexibility services. However, it needs to be weighed against the needs of the specific grid for flexibility services and how well developed the flexibility market is.

In the selection process an important aspect was that a specific technic does not determine the smartness of the grid, it is the result that does. Another important aspect was availability which is a criteria that was analysed together with the reference group. If the collection of data was judged to be too complicated the indicator has not been selected. The reference group pointed out that smart meters can lead to simpler data collection in some cases. The minimum smart meter requirements are to be implemented by 1 January 2025 by the distribution system operators (DSOs), see article [4]. The reference group also helped define the indicators to make them clearer and to make it possible to report them.

INDICATORS

In this section the selected indicators are described. Table 2 shows which aims of the smart grid implementation that each indicator falls under.

Currently collected indicators

Currently Ei collects data from the Swedish transmission system operator (TSO) and the DSOs, divided into local and regional DSOs. Local DSOs have a monopoly within an area up to a given voltage level, while the rest are referred to as regional DSOs. The collected data is primarily used for the revenue cap regulation and to monitor the grid companies' compliance with regulations. The Swedish power system and its regulations are described in [5] and [6]. From currently collected data Ei has identified a set of indicators that can be used in the assessment and monitoring of the smart grid development.

Continuity of supply

It is important for a smart grid to have a high continuity of supply (CoS). Furthermore, it follows from recital 83 of the Directive that the frequency and duration of the power interruptions should be monitored by the NRA. Ei collects data on power outages per customer from the DSOs annually, see article [7]. From this data indicators such as System Average Interruption Duration Index (SAIDI) and System Average Interruption Frequency Index (SAIFI) can be calculated.

Table 2 The aims of the smart grid implementation. ET – energy transition. EE – energy efficiency. RR – Resilient and reliable electricity grid.

Indicators and indicator categories	ET	EE	RR
Continuity of supply			x
Grid losses	x	x	x
Utilisation rate of the grid		x	
Local production	x		
Voltage quality	x		x
Level of substation automation		x	x
Use of flexibility services	x	x	
Total capacity of connected energy storage	x	x	
Use of dynamic line rating	x	x	x
Utilisation rate of transformers	x	x	x
Network tariffs	x	x	
Hosting capacity from RES	x	x	
Electrification of the transport sector	x	x	

Grid losses

A smart grid needs to be efficient and have low grid losses. Additionally, recital 83 of the Directive states that the reduction of grid losses should be monitored by the NRAs. Grid losses and the total amount of energy distributed in the grid is currently being reported annually to Ei by the TSO and the DSOs [6]. From this data the percentage of the grid losses can be calculated to allow the grid losses to be compared between grid companies and take into account that a reduction in grid losses can be the result of e.g. warm weather (for Sweden), and not a more efficient grid utilisation.

Utilisation rate of the grid

Evening out loads and reducing peaks can increase the capacity in the grid. This can result in more end-users being able to connect to the grid without investing in more capacity. An even load also reduces grid losses. Another benefit of reduced peaks is the reduced cost for the overlying grid.

Ei collects two indicators that measures how evenly distributed the load is in the grid. These are the average load factor (Lf) and the load factor (η) (only reported by the DSOs). Lf is a measurement of how even the load is on average per day and per year (Lf is defined in article [6]). Similarly, η is a measurement of how even the load is in the grid, but it only takes the four highest daily peaks into account instead of every daily peak (η is defined in a parallel CIRED paper).

The two indicators complement each other since an evened load has different effects and benefits for the grid depending on if it is the highest peaks that are reduced or if all the daily peaks are reduced and thus having a more even load during the whole day.

Local production

Due to the ongoing energy transition, large central power plants are being replaced by distributed renewable energy sources (DRES). Though DRES can be installed in a smart as well as a regular grid, the amount of power-generating facilities (PGFs) can give an indication of the needs, challenges, and possibilities in the grid, thus giving the preconditions for a smart grid.

The TSO and the DSOs annually report the number of PGFs connected to the grid and the number of small (≤ 1 500 kW) PGFs connected to the grid, and the amount of supplied energy from these PGFs. Local DSOs also report the number of micro (≤43,5 kW) PGFs and the amount of supplied energy from these. Small (≤ 1 500 kW) and micro (≤43,5 kW) PGFs often consists of DRES and can therefore act as an indicator of the preconditions of a smart grid.

Newly adopted indicators

Voltage quality

The energy transition can entail more challenges for the voltage quality in the grid. This is among other things due to the increase of RES. Input impedance is an electrical characteristic of the power grid that is used to dimension the area and length of electrical conductors and fuses. In local networks the input impedance for end-users indicates the grid strength and ability to withstand changes in voltage and therefore the risk of voltage quality issues for the end-users. Hence, the share of end-users with an input impedance between 0,5 and 1,0 Ohm as well as the share of end-users with an input impedance 1,0 Ohm in distribution networks is used to measure voltage quality. This indicator will be reported by the local DSOs.

Level of substation automation

In the Directive, recital 83, it is suggested that the development of remote monitoring and real-time control of substations should be monitored by the NRA. The indicator level of substation automation aims to do that. From a technical perspective, smart grid technologies are often about using IT- and communication technology as well as advanced measuring, monitoring and control. Substations are important junction points since they make out the points between different voltage levels in the grid. With an increased need for electricity from the transport and industry sector there will be more requirements on the operation of the grid concerning the transformation of electricity. Automation is a prerequisite for a faster response of the grid, lower grid losses and shorter interruptions for the customers. This is not only true for the substations. A higher level of automation in all the grids stations can result in a more efficient use of the grid as well as shorter and fewer interruptions.

For the TSO and the DSOs, the level of substation automation is considered based on three levels, measurement, control and full-scale self-regulation. Both current and voltage are assessed for all three levels. [1]

Use of flexibility services

The amount of variable production such as solar power and wind power is increasing and will likely continue to increase in the future. The result of this is that production cannot be adapted to consumption in the same way as before when the share of planned production was higher. One way to solve this is with the use of flexibility. Flexibility services can, among other things, contribute to solving grid problems such as frequency containment processes, power shortages and capacity shortages, and contribute to reduced grid losses.

The TSO and the DSOs will report a set of different information about procured flexibility from a market and via bilateral agreements for this indicator [1]. This information includes number and amount of procured flexibility services for upregulation and downregulation on a market. It also includes information about number of bilateral agreements and times they have been used, and amount of contracted and procured power with consumers and producers via bilateral agreements.

Total capacity of connected energy storage

The Swedish electricity grid is today characterised by a lack of capacity. With an increased power demand in the future, there is a risk that transmission and distribution problems that already exist continue to grow and it is also likely that new bottlenecks emerge. For this reason, it is important that electrical energy can be stored and then supplied as needed. Both the TSO and the DSOs will report the total capacity of connected energy storages in their grid that are not owned by the system operators (SOs).

Use of dynamic line rating

Distribution and transmission systems have traditionally been passive with centrally located generation; energy has flown from the transmission grid down to lower voltage levels. With the addition of distributed production at all voltage levels, there is a need for the grid companies to actively manage the flows in the grid, which is something that the transmission grid company already does today. In the Directive, recital 83, dynamic line rating is mentioned as one of the indicators that can be used to assess the smart grid development. Dynamic line rating involves using the capacity of a line in a more efficient way by continuously assessing the transmission capacity of the line by, for example, considering parameters such as wind speed and temperature. The technology promotes better use of the grid today and in the future.

It is only the TSO and the regional DSOs that will report this indicator. They will report information about the number of lines with automatic dynamic line rating and their aggregated length.

Utilisation rate of transformers
The load factor is only reported by the DSOs to Ei, see above. It is also relevant to assess how even the load is on the transmission level over time and the TSO will therefore start to report an equivalent indicator. Smart grid technology can be used to even out the load, and it can also be used to increase the capacity utilisation when suitable. Ei is therefore going to follow the capacity utilisation of the transmission grids transformers.

For this indicator the TSO will report information about the mean value and the standard deviation of the ratios between the average power and the maximum power for each transformer during a calendar year. Also, information about the mean value and the standard deviation of the ratios between the maximum power and installed capacity for each transformer during a calendar year.

Network tariffs
Traditionally grid companies have been passive when it comes to developing grid tariffs that are designed after loads and their variability. By time-differentiating one or more fee components in the tariff, incentives are created for grid customers to shift or reduce their electricity consumption from times when the load on the grid is high to times when the load is lower. Such a tariff can be designed with respect to both power or energy and can be differentiated to different extents such as seasonal or with critical-peak pricing. Time-differentiated grid tariffs can thus contribute to a more even load on the grid and to solve problems such as power and capacity shortages. Ei therefore considers it relevant to follow the development of time-differentiated network tariffs.

The TSO and the DSOs will report the share of customers that have a time-differentiated grid tariff if the TSO and the DSOs offers these types of tariffs. The SOs will also report an account of what types of time-differentiated grid tariffs that they use.

Effects on the grid companies
In 2024, the DSOs and the TSO will submit data to Ei concerning the previous year for the indicators described above with an exception for DSOs with less than 5 000 customers. This will result in an increased amount of information to report to Ei, which will mean increased administrational costs.

Indirect indicators and indicators from external sources

Hosting capacity for renewable energy sources
An increased share of RES leads to a need for flexibility in the grid, but it also leads to challenges in terms of voltage quality. One of the aims with the introduction of smart grids is the integration of RES. It is therefore important to examine the potential for integrating RES into the grid. Hosting capacity for RES shows how much capacity from RES that can be connected to the grid. In article *Performance indicators for quantifying the ability of the grid to host renewable electricity production* it is described that grid losses and several voltage quality parameters are needed to estimate the hosting capacity for RES [8].

Quantifying the indicator needs to weigh several factors in the grid and it is not obvious how this should be done. This makes the indicator complex to decide explicitly for a grid. The attempts made to define an indicator did not result in anything tangible. Instead, the indicator voltage quality in combination with the indicator grid losses will be used to give an estimate of the grids hosting capacity for RES.
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Electrification of the transport sector
In the future the transport sector is expected to in large be electrified to meet the climate goals. This will lead to an increased need for charging stations, that results in an increased need for power and capacity. This will in turn lead to higher requirements for the distribution of electricity. Smart grid solutions will be needed to reduce the negative effects that can arise in the form of a lack of capacity, frequency problems and voltage quality problems. The electrification of the transport sector also means opportunities for a smart grid by controlling the load to evening out the load and reduce the lack of capacity. The charging of electrical vehicles can be done traditionally without regard for the grid or by smart charging where available capacity is considered or with Vehicle to Grid (V2G) where the vehicle can be used as an energy storage.

Ei will not collect an indicator for this area. Due to the grid companies not having the knowledge of the number of charging stations in their grid. It has also been found that sufficient information about electrification of the transport sector can be found from other sources.

Context to the indicators

Besides the indicators described above Ei collects other information from the TSO and the DSOs that can be used to compare indicators between grid companies. The information can also be used to give context to the grid companies preconditions in the assessment of the smart grid development. The following information from the data that Ei collects from each SO has been identified as relevant:

- Length of power lines divided by different voltage levels and choice of technology (overhead lines and underground cables)

- Number of network stations (only reported by the local DSOs)
- Number of end-users divided into; all consumers, all PGFs, small (≤ 1 500 kW) PGFs and micro (≤43,5 kW PGFs (only reported by the local DSOs))
- Number of end-users per customer category
- Number of connection points to contiguous, underlying and overlying grids
- Amount of consumed energy divided by different voltage levels
- Amount of supplied energy from all PGFs, small (≤ 1 500 kW) PGFs, micro (≤43,5 kW) PGFs (only reported by the local DSOs)
- Total subscribed power in the grid
- Maximal power fed into the grid
- Total installed transformer power in network stations (only reported by the local DSOs)

ASSESSING AND MONITORING THE SMART GRID DEVELOPMENT

Every grid is unique and has different preconditions and needs of smart grid technology. The smart grid development should not be a goal in itself, but the aim should be to ensure a resilient and flexible grid that promotes energy efficiency and the integration of RES. The recommendations that Ei will publish every two years in accordance with the Directive will therefore vary for the different grid companies and with time.

The conclusions and recommendations for the smart grid development needs to be based on several indicators. Smart grids are complex and involve both new technology, new services, and new conditions. Many of the indicators are interdependent and need to be analysed together with the other indicators to get the full picture. For example, a grid can have many installed charging stations at the same time as the grid has a high share of RES and a relatively high level of substation automation. Without putting this in relation to other indicators such as voltage quality and continuity of supply, it is not possible to assess whether this degree of automation should be considered sufficient or not. This also depends on other uncontrollable factors such as the number of end-users, their consumption patterns, and the topography of the grid. In the same way, a high degree of flexibility services or time-differentiated network tariffs does not automatically mean, for example, a good utilisation rate of the grid. The recommendations will thus be based on the conditions within different grids and depend on a complex relationship between indicators. It is also important to note that if one indicator increases it may have a negative impact on another indicator, thus reinforcing the importance of looking at all the data as a whole.

CONCLUTION AND FUTURE WORK

The indicators described in this article will be used to assess the smart grid development in Sweden. Some of the indicators are already being collected by Ei and some will first be reported in 2024 (with respect to data for 2023). Based on the results of the indicators Ei will every two years publish a report and give recommendations for the smart grid development in accordance with the Directive. To give a picture of the smart grid development, the indicators need to be analysed together and over time. The set of indicators described is not to be seen as an exhaustive list. There could also be other indicators to assess and monitor the smart grid development from external sources.

Ei will evaluate the indicators every three years, since technology is constantly changing. New technical solutions can quickly arise, and this can change the conditions for fulfilling the Directive. Renewed evaluation of which indicators are chosen for assessing and monitoring the smart grid development is therefore of importance.

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