MONITORING VOLTAGE QUALITY IN SWEDEN

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ABSTRACT

This paper presents the results for the monitoring of voltage quality that Swedish Regulatory Authority (Swedish Energy Markets Inspectorate, Ei) has performed during the year 2022 for the voltage quality during the period 2016-2021.

Monitoring the voltage quality is an important task for all the European member states. The aim of this article is therefore to enhance the transparency and provide other member states with an overview on how Sweden is working to ensure that the DSOs continue to work to achieve and maintain a good voltage quality in their grids. The monitoring of voltage quality described in this paper also gives useful knowledge of the Swedish power quality regulation EIFS 2013:1.

INTRODUCTION

Sweden has approximately 170 distribution system operators (DSO) (mostly local DSOs with a monopoly within an area up to a given voltage level, while the rest are referred to as regional DSOs) and one transmission system operator (TSO); all with different conditions regarding size, ownership, and clime/terrain. Regional DSOs distribute electricity to local DSOs and sometimes directly to high-consumption customers, while local DSOs distribute electricity to local customers. There are also local power generators that are directly connected to both regional and local grids.

It is important to ensure that the power supplied by the system operators is of good quality, as electricity with poor quality is dangerous and can be costly for both utilities and customers. Power quality can have a significant impact on the performance and cost of a power system.

Voltage quality (VQ) in the power grids relates to how well the system operators manage the voltage quality at the supply points. Today's energy transition imposes several challenges on the power grid. The transition leads to an increase in more distributed generation, increased number of prosumers, more inverter-connected devices, changes in customer load and bilateral flows. Many of these tendencies can have a negative impact on the voltage quality unless the system operators work proactively to mitigate potential problems. The national regulatory authority has an important role of the voltage quality supervision to reveal potential problem areas and to ensure regulatory compliance.

Costs of poor voltage quality

It is usually difficult to assume the costs from poor voltage quality, but studies show that the costs can be very high. For instance, a study [1] carried out in 25 European countries showed that the cost of voltage quality failures exceeds EUR 150 billion industries (industries account for 90 % of the amount). Voltage drops, short interruptions, overvoltages and transients stands for 80-90 percent of the costs. The main cost drivers are damage to equipment and losses of working time.

EXISTING SUPERVISION

The regulation of voltage quality is based on the Electricity Act [2], Paragraph 8 chapter 4, which states that the supply of electrical power shall be of good quality. In the secondary regulation EIFS 2013:1 [3], chapter 7, states the limiting values for the voltage phenomena e.g. voltage unbalance, harmonic voltage, slow voltage variations, voltage dips, voltage swells and rapid voltage changes. The regulation also states that the system operators are responsible for ensuring that the voltage is of good quality for all grid users in their respective grid. A paper describing the predecessor of EIFS 2013:1 was presented at the 2011 CIRED conference [4]. Since then, minor updates have been made to the section on harmonics.

Ei conducts supervision to ensure that DSOs maintain voltage quality in accordance with the regulations. Ei works with both a systematic supervision method and a supervision following reports to Ei from customers. However, Ei does not collect data on voltage quality. Therefore, Ei has decided to systematically supervise all DSOs in Sweden regarding their VQ responsibilities over a five-year period between 2021-2025. Circa 30-35 DSOs are supervised each year during the period.

To obtain as wide a sample as possible, the DSOs are selected based on their size (both small and large DSOs are selected), type of grid (rural, urban and city) and geographical spread in Sweden (North, Centre and South)

in each supervision year. However, Ei also wants to compare similar-sized DSOs. Ei therefore decided to include the three largest DSOs, accounting for about 14-15 percent of all Swedish end-users each (while the rest of the DSOs each account for 0-5 %), in the 2022 supervision. At the end of each supervision, Ei publishes a report on the results of the supervision.

Regarding the supervision initiated after reports from customers, Ei receives only a few complaints on poor voltage quality each year. However, this paper focuses solely on the systematic supervision.

Aims of the supervision

The aims of the supervision are to:

- verify that DSOs comply with the regulation and ensure that DSOs take measures, both in the short and long term, to ensure that the supply of electricity is of good quality,
- identify areas where regulatory improvements may be necessary and
- identify areas where there is a need of information to DSOs and/or end-users to clarify how the regulation should be interpreted and complied.

Method of the supervision

The method of the supervision consists of two parts. The first is about the DSOs' actions on customer complaints regarding VQ. The second part is about how the DSOs foster a good VQ in their grids.

The most recent supervision of voltage quality, the second round in the five-year plan, was carried out in 2022. A selection of 30 DSOs submitted information on complaints they have received regarding VQ during 2016-2021, how they work to comply with VQ regulation and how they see the development of VQ in their own grid. These 30 DSOs have around 2 840 000 end-users together, accounting for 51 percent of all customers in Sweden. The large share of end users is because Ei decided to supervise the three largest DSOs in the same year.

The DSOs were requested to provide a list of complaints they have received from their customers regarding voltage quality between 2016 and 2021. The list of complaints must include information on:

- the date of the complaint,
- the reason of the complaint,
- the cause of the fault,
- whether the fault was temporary or ongoing,
- customer category,
- how the complaint was resolved,
- whether a VQ measurement was conducted,
- whether the values during measurement met the standards for good VQ (EIFS 2013:1, Chapter 7),
- the measures taken to fix the fault and
- the date when the measures were implemented.

To increase the understanding of the DSOs' work on voltage quality, Ei, asked additional questions to the DSOs:

- describe their methods for ensuring good VQ and their systematic work with VQ,
- requirements that DSOs impose on their customers regarding voltage emissions in new connections,
- the number of phenomena per year that they consider acceptable to fulfil the regulations on good VQ
- the methods used to ensure that the supply of electricity meets the requirements for good VQ,
- DSOs' perspective on and approach to future developments in the electricity grid with regards to voltage quality, such as strategies to minimize VQ phenomena and methods used to measure VQ in the grid and
- does the DSO evaluate the costs of alternative methods to maintain good VQ and if the DSO had observed any deterioration or improvement in VQ over the last ten years.

RESULTS OF THE 2022 SUPERVISION

Out of the 30 selected DSOs, only 29 submitted complete information on their customer complaints and therefore only data from these 29 DSOs are presented in this paper. However, all 30 DSOs answered the other questions and those are presented.

In total, the DSOs received 598 complaints on VQ from their end-users between 2016 and 2021. The DSOs received most complaints from households, accounting for 76 percent of all complaints received. End-users within commercial services and industry end-users filed the second and third largest number of complaints, 5 and 4 percent of the total complaints respectively.

Furthermore, the supervision shows that the DSOs have determined, by measuring the VQ at the connection point, that the VQ did meet the standards set in EIFS 2013:1 for 247 (41.3 %) complaints and that it was inadequate for 114 (19.1 %) complaints. The DSOs did not measure the VQ for all the complaints where the VQ was found poor, sometimes the fault behind the compliant was found by the DSO or the customer before an analysis was initiated.

Fluctuations generated most complaints

In total, almost a third of all complaints reported in the 2022 supervision was regarding flicker or voltage fluctuations, making them the most common reason for end-users to complain about VQ. Each year, between about 30 and 45 percent of the complaints were on flicker or voltage fluctuations, while abnormal voltage (unspecified), other disturbances or vague description and voltage dips each accounted for between 7 and 27 percent of the yearly complaints, see Figure 1. A similar distribution of complaints was seen in the 2021 supervision, where 30 other DSOs shared complaints received during 2019-2020.

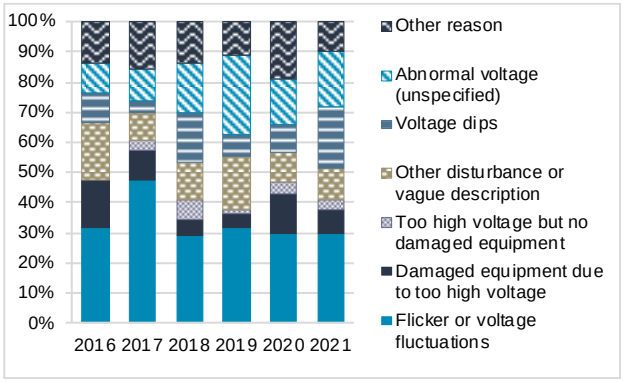

Figure 1: Distribution of phenomena causing customers to complain about VQ per year 2016-2021.

Where was the fault located?

Most often, for 177 of the total 598 complaints (29.6 %), the fault was located in the DSOs' grids, while for 142 complaints (23.8 %), the fault was located in the customer's own facility. For 81 complaints (13.4 %), the underlying fault was never found. For 161 complaints (26.9 %), the VQ was either adequate or the fault was of other origin. The distribution of the fault's location does not differ that much for the six years of the supervision carried out in 2022, see Figure 2. A similar distribution was seen in the 2021 supervision.

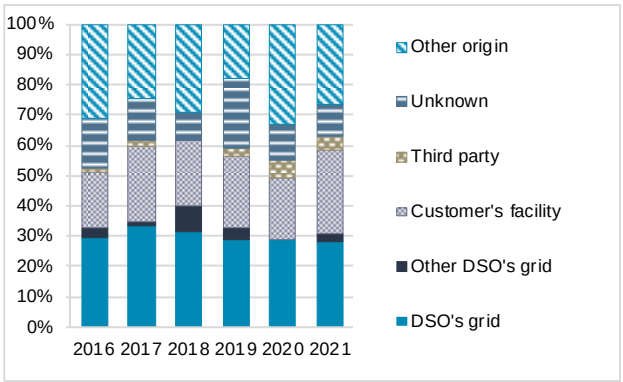

Figure 2: Distribution of where the fault, causing the customer complaint, was located per year 2016-2021.

Considering the 114 complaints where measurements by the DSO found the VQ to be poor, the faults were most often located in the DSO's grid (89 complaints, 76.3 %). In 9 cases (7.9 %), the customers were found to have caused the faults themselves by, for example, exceeding the limits of their power connection. In 12 cases (11.5 %), the fault was of other origin.

Measures taken by the system operators

In total, the DSOs took measures to improve the VQ in their grids for 248 (41.5 %) complaints out of the 598, about 35 and 50 percent per year, see Figure 3. About half of the measures taken were large investments to strengthen the grid or to replace larger components, such as transformers, while the other half was smaller investments, for example repairing damaged components or replacing fuses.

The DSOs did not take measures for 342 of the 598 complaints (57.2 %), either because the VQ met the requirements of the regulations or because the poor VQ was caused by the customers themselves or a third party. The remaining 11 complaints are still under investigation by the DSOs.

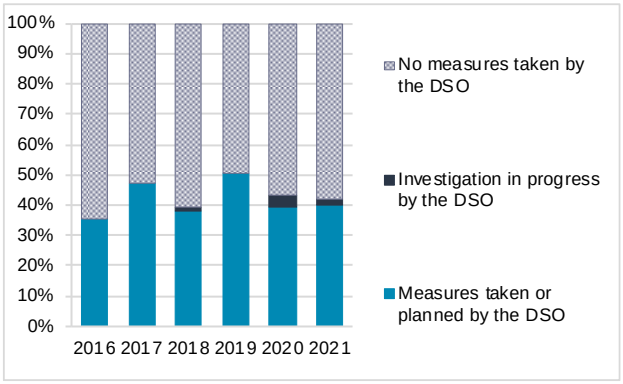

Figure 3: Distribution of measures taken by the DSOs in response to the customer complaints per year 2016-2021.

Out of the 114 complaints where analysis found the VQ to be poor, the DSOs took measures to make improvements in their grids for 97 (85.1 %) of the complaints. Thus, the DSOs made improvements in their grids in 134 cases even though the end-user's VQ was never found to be poor. However, in some of these cases, the DSOs already knew about flaws in their grids, and had already planned actions to improve the power quality before they received complaints from end-users. In other cases, no analyses of the VQ were needed as it was already obvious from the complaint which measures were required. Also, a share of these improvements relates to strategic developments of the grid, such as renovations, reinforcements, or expansions. For 15 of the 114 complaints (13.2 %) no measures were taken by the DSOs as the responsibility for the poor VQ was found elsewhere. Two complaints are still under investigation by the DSOs.

How is good VQ maintained?

It is important for DSOs to ensure that the supply of electricity meets the requirements on good VQ defined in EIFS 2013:1. New grids must be designed and constructed in a way that ensures good VQ in both the short and long term, considering developments and changes in technology, power generation and consumption.

Therefore, Ei asked, via a multiple-choice question, the DSOs to explain how they ensure that the supply of electricity meets the requirements for good VQ. The 2022 supervision was the first where multiple-choice questions were used. The answer options were based on the most common answers given by DSOs in previous supervisions. For example, the options in Table 1 below are based on the most mentioned measures taken by DSOs to ensure a good voltage quality in previous supervisions.

Different measures are taken by the DSOs to ensure that the supply of electricity meets the requirements for good VQ. Table 1 below presents the responses from the DSOs. All DSOs answered that they construct their grids to meet the requirements. Most of the DSOs also stated that they investigate notifications on poor VQ from their end-users and measure the VQ at the connection point to validate the quality. A few DSOs assert that they have technical guidelines for VQ but also do calculations on VQ when needed.

Table 1: Measures taken by the 30 DSOs to ensure a good voltage quality

Measures Taken by DSO	Number of DSOs
Continuous monitoring of VQ in the grid or specific areas (example: receiving stations, distribution stations, sub stations)	25
Using portable power quality meters	27
Designing grids to meet requirements for new construction	30
Conducting calculations on existing grid	28
Investigating VQ by indication	29
Automatic voltage regulation	26
Active communication with end-users	24

It should be mentioned the overall result of the answers is quite similar. This is probably due to the design of the questions. The 2020 supervision was the first where DSOs were asked to answer multiple choice questions, instead of giving free text answers, allowing them to select more than one option. This may have affected the results and the analysis.

Future voltage quality developments

When asked on their expectations on future trends in voltage quality, some DSOs believe more issues with poor VQ could occur in the future as more loads and small-scale generation units are connected to the grid. Some pointed out that an increase of electrical vehicles could be a future risk that has to be managed, especially in weaker grids. While most DSOs raised concerns about the future, one DSO argued that it has not yet seen any trends of negative VQ developments in their grid after increasing input from small scale generation or connecting new loads.

The DSOs said that working more proactively with improvements in their grids will be important to minimize the risk of future issues with VQ. Some DSOs also thought that flexibility services, particularly load balancing services, could be useful to prevent poor VQ by balancing intermittent generation and stabilizing weak grids. However, a few DSOs raised concerns that some flexibility services, such as batteries for energy storage, could cause poor VQ as loads in the grids could increase when batteries are being recharged.

CONCLUSIONS

The main conclusion of the 2022 supervision is that the voltage quality in Sweden is relatively good. Ei sees a willingness from the DSOs to meet the requirements of the VQ regulation.

Based on the reported customer complaints, the most common phenomena in the Swedish grid are voltage variations, flicker, and abnormal voltage. The supervision showed that there is a difference between how the DSOs record the customer complaints.

There are not too many complaints on poor VQ from the end-users, and the DSOs are investigating the complaints and are taking measures to improve the VQ when it is found to be poor. The DSOs reported that the VQ complaints received from their customers have resulted in measures which have generally been implemented within a reasonable time. However, Ei has observed that there is a variation between the DSOs in how long time they take to resolve the problem causing the poor VQ due to their individual resources.

Further, Ei welcomes the fact that most DSOs measure VQ in strategic locations on a continuous basis. It is important that the DSOs are engaged in the future development of the VQ in their grids and that they are considering different methods and strategies to achieve and maintain good VQ. A poor VQ negatively affects the equipment, leading to increased costs for maintenance and repair. Achieving good power quality is a combination of long-term work and the ability to quickly react on issues that occurs in the grid.

Based on the results of the 2022 supervision, Ei concludes that it is becoming increasingly important to monitor the VQ in the grid. This is due to factors such as the increase in decentralized and intermittent electricity production because of the energy transition, the integration of more electronic components but also changes in consumption patterns.

Further, the supervision gives useful insights to the ongoing revision of Ei's regulation on quality of supply (EIFS 2013:1). Limits for flicker severity are added to the chapter on requirements for voltage quality and the chapter is partially harmonized with the latest European technical standard on Voltage characteristics of electricity supplied by public electricity networks EN 60150.

It is not only Ei that needs to monitor the VQ in the power grid. The impact of the energy transition on VQ is ongoing in the entire EU and the monitoring of VQ will be crucial to maintain and improve a good VQ in the future.

FUTURE WORK

Ei will continue to work with the systematic supervision until 2025. Ei considers reviewing the systematic supervision method when the new smart meters, capable of measuring VQ parameters, are installed at every Swedish end-user in 2025.

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