Incentivizing Continuity of Supply in Sweden

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***Abstract*— A revenue cap regulation for electricity distribution system operators (DSOs) has been in place in Sweden since 2012. The national regulatory authority for energy, the Swedish Energy Markets Inspectorate (Ei), determines a revenue cap for each network operator for a period of four years. This paper describes the new incentive scheme for continuity of supply that is first applied in the period 2016-2019. Depending on the performance of the DSO, the incentive scheme may result in a reward or penalty on the financial return to the DSO.**

In the new incentive scheme, the performance of all DSOs at local level is benchmarked to set individual baselines for each company based on the customer density. The performance indicators SAIDI and SAIFI are differentiated between different customer groups, and the indicator $CEMI_n$ is introduced. This paper aims to act as reference material and inspiration to others as well as a chance for Ei to receive feedback valuable for future development.

***Index Terms*-- Continuity of supply, incentive scheme, power system reliability, revenue cap regulation**

I. Introduction

A. *Why regulation of quality is needed*

Electricity is a vital part of today´s society. Customers are highly dependent on a reliable continuity of supply (CoS), and power outages lead to considerable costs for the society. The costs for electricity interruptions in Sweden were estimated to ~140 million euros[1] during 2013 [1].

Distribution of electricity is considered as a natural monopoly while the trade is de-regulated since 1996. Due to the lack of competition, electricity distribution system operators (DSOs) are subject to regulation to promote quality of supply and to ensure fair prices. One of the roles of the DSOs is to optimize the continuity performance in a cost effective manner. The role of the regulator is to ensure that this optimization is carried out in a correct way with respect to the customers' expectations and their costs due to power outages [2].

The electric power system in Sweden can be divided into three levels: transmission operated by a government owned transmission system operator (TSO), sub-transmission operated by a few (the four largest own about 99,7 %) regional DSOs and a distribution level operated by ~170 local DSOs with significant different sizes, different kind of ownerships and other different characteristics. The sub-transmission level, also called regional networks, is the link between the transmission and distribution levels [3]. The sub-transmission level has an incentive scheme which is different, see chapter IV.

One of the incentive schemes applied in the Swedish regulation of DSOs aims at promoting socioeconomically desirable levels of CoS. The reward or penalty will impact the financial return to the DSO. In Sweden, an incentive scheme for CoS was first introduced by the Swedish regulator during the regulatory period 2012-2015. For the second regulatory period, 2016-2019, it was possible to further improve the incentive scheme when more detailed outage statistics were available [4].

B. *Previous regolatory period 2012-2015*

An ex-ante regulation of electricity network tariffs has been in place in Sweden since 2012. Ei sets a revenue cap for each DSO and the TSO for a regulatory period of four years at a time. The purpose of the revenue cap is that DSOs shall obtain reasonable coverage for their operational costs and reasonable return on the invested capital. The incentive regulation that is applied for DSOs in Sweden can mainly be classified as an output based regulation. Output based regulation is still a relatively new concept in electricity network regulation, and means among other things that incentive schemes are used to focus on the DSOs' performance.

During the first regulatory period 2012-2015, the performance of the DSOs was assessed using the indicators SAIDI and SAIFI. The reward or penalty for each DSO, i.e. the adjustment of the revenue cap, was calculated using each DSO's SAIDI and SAIFI, in combination with customer interruption costs. The indicators for each DSO were compared to their own historical levels. The interruption cost was reconstructed using the same parameters for all customer groups, an aggregated customer interruption cost, meaning that the differences in costs between customer groups did not affect the outcome of the regulation. The costs were however divided based on whether the outage was notified or not.

[1] 1 EUR ≈ 9.5 SEK (April 2016)

C. Different approches incentivizing continuity of supply

On a European level, a large number of regulators have adopted regulatory instruments to maintain or improve the CoS [2],[5],[6]. A summary of if and how different countries take it into account can be found in [7].There are two main approaches for determining standard CoS levels (referred to as baselines later in the paper) to compare the measured outcome. The first is to take into account performance over time (history), e.g. the method used in Italy and the method used in Sweden 2012-2015. The other is to use a mathematical model, e.g. the method used in Norway. From 2016, a combination of both approaches is used in Sweden, see section III.C.

D. Swedish regulation from 2016

This paper describes the new incentive scheme which aims to improve the effectiveness and accuracy of the regulation. The method at local level (see chapter III) includes the following main principles:

- The incentive rate for rewards and penalties is calculated based on the interruption costs for a number of different customer groups.
- A baseline is defined for each performance indicator and DSO. For the indicators SAIDI[2] & SAIFI[3] the baselines are defined using a benchmarking method where performance is set as a function of customer density.
- A new indicator, $CEMI_n$[4], is used for adjusting the incentive levels. The aim with using this indicator is to decrease variations in reliability on customer level within the same DSO area. SAIDI and SAIFI measure only average system reliability and do not show the variation in reliability on customer level.

This paper is a summary of a Swedish report [4] which treats the subject more thoroughly. For the period 2016-2019, another new incentive scheme was also introduced as a part of the Swedish revenue cap regulation. That incentive aims to promote efficient utilization of the grid and is described in [8].

E. Outline

Chapter II summarizes the objectives of the new regulation, chapter III describes the incentive scheme for DSOs at local level and chapter IV describes briefly how the incentive scheme works for DSOs at sub-transmission level and the TSO. Finally, chapter V presents the conclusions.

II. Objectives of the Incentive Scheme for Continuity of Supply

To ensure that each customer have a sufficient level of CoS, the Swedish legislation contains guaranteed standards concerning e.g. outages shall never be longer than 24 hours, a costumer should not have more than 11 outages each year, voltage quality and mandatory individual customer compensation for outages ≥12 hours [9]. The Swedish regulator cannot force the DSOs to provide a higher level than the minimum requirements, but if it is socioeconomically motivated to improve the quality of supply on a system level, the DSOs should be given incentives to do so. The new regulation aims to give incentives for an optimal level of CoS from a socioeconomic perspective. The objectives of the new regulation can be summarized as follows:

1. The costs for interruption shall be more closely tied to the societal costs. This is achieved by using a detailed customer interruptions cost method when calculating the rewards and penalties.
2. The regulation incentivizes a higher level of CoS.
3. DSOs that already have a high CoS shall be incentivized to maintain that level.
4. The regulation gives incentive to discourage unreasonable differences in CoS between networks.

Objectives 2-4 are achieved by using a new benchmarking method when setting the baselines of SAIDI and SAFI.

5. The regulation gives incentive to discourage unreasonably high differences regarding CoS within networks by applying the indicator $CEMI_n$ (currently $CEMI_4$ is used and is defined later in section III.B).

III. Incentives for DSO:s at Distribution Level

The incentive scheme for CoS for DSOs consists of several parts. A schematic description of the incentive calculation is shown in Fig. 1 The index k represents the five customer groups, k={industrial, residential, agricultural, public service, commercial service}.The incentive is calculated based on the customer interruption costs, the performance using SAIDI, SAIFI and $CEMI_4$ (see section III.B) compared to the baseline, and finally adjusted if the incentive is exceeding a certain level. Each part is described in greater detail in the corresponding section of this chapter.

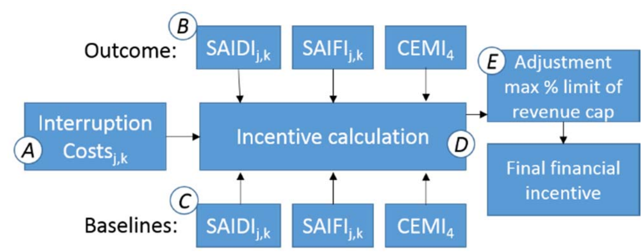

Figure 1 Schematic description of the incentive calculation.

A. Interruption costs for different customer groups

Society's valuation of a reliable grid can be estimated by the costs associated with interruptions in electricity supply. The optimal level of CoS is defined as the level that minimizes the total societal costs for interruptions and the costs for delivering that level of CoS [10]. At low levels of CoS, the customers' costs for interruptions are high. At high levels of CoS, the costs for the electrical network are high. The optimal level of CoS lays somewhere in between these extremes. To be able to reach the socioeconomic optimal level of CoS, it is of great importance how the customer interruption costs are derived. A good estimation of customer valuation of quality is a key element of reward and penalty mechanisms [10][11]. The customer cost depend on many factors, such as the timing and the length of the interruption, and what activities that were interrupted for the customer. One other important factor is if the

[2] System average interruption duration index
[3] System average interruption frequency index
[4] Customers experiencing multiple interruptions

interruption is correctly notified in advanced or not. Studies have shown that different customer groups have significantly different interruption costs and therefore it is recommended to estimate them separately for the different groups [12].

In the regulation for the period 2016-2019 the customers are differentiated into five different customer groups; household, industry, agriculture, commercial service and public service. Since 2010, the DSOs have been reporting interruption data to the Swedish regulator on a customer level, where each metering point is associated with a standard industrial classification (SNI 2007). That allows differentiations into customer groups [4].

The interruption costs used in the regulation are based on an investigation performed in 2003-2004 [13], which was updated using a new normalization method in [14] according to the recommendations from CEER [12]. The costs are formulated as parameters given in cost for interrupted energy (SEK/kWh) and cost for interrupted power (SEK/kW) for each customer group. Furthermore, a differentiation is made between notified and unnotified interruptions. The cost parameters used in the regulation are available in [4]. A new interruption cost study is currently ongoing, that can be input in future regulation.

B. Indicators for continuity of supply

The indicators used for the second regulatory period of the regulation are SAIDI [hours or minutes / customer, year], SAIFI [number of outages / customer, year] and $CEMI_n$. SAIDI gives information about the average interruption time per customer and year, as follows in (1).

$$SAIDI = \frac{Total\ customer\ interruption\ time}{Total\ number\ of\ customers} \quad (1)$$

SAIFI gives information about the average interruption frequency per customer and year, as follows in (2).

$$SAIFI = \frac{Total\ number\ of\ customer\ interruptions}{Total\ number\ of\ customers} \quad (2)$$

$CEMI_n$ is designed to show the share of the customers experiencing n or more interruptions per year, as in (3).

$$CEMI_n = \frac{Total\ number\ of\ customer\ experiencing\ at\ least\ n\ interruptions}{Total\ number\ of\ customers} \quad (3)$$

The indicators SAIDI and SAIFI will be calculated based on each customer group for both notified and unnotified interruptions. For unnotified interruptions, SAIDI and SAIFI are based on long interruptions (>3 minutes) which have a duration time <12 hours. For notified interruptions all long interruptions are included. The reason for excluding unnotified interruptions ≥12 hours is that the DSOs, according to the Swedish Electricity Act are obliged to pay compensation to customers that have experienced such interruptions, see e.g. [15]. Thus, the DSOs already have incentives to avoid interruptions ≥12 hours. Interruptions are reported separately to the regulator depending on the length of the interruption.

Both SAIDI and SAIFI are aggregated and normalized indicators which do not take into account variations in continuity of supply within a specific network area. This means that there is a potential risk that DSOs can boost the performance indicators in areas with high customer density at the expense of areas with low customer density within the same network. In order to counteract this possibility, the indicator $CEMI_n$ has been introduced. $CEMI_n$ is used to reduce the size of the penalty or reward calculated based on SAIDI and SAIFI, depending if $CEMI_n$ has improved or worsened. The regulator has determined that n should be equivalent to what is defined as good quality of electricity distribution. According to the regulation in Sweden, the quality is considered good (with respect to number of interruptions) if the number of long interruptions is less than 4 per calendar year, which motivates the value for n to be set to 4, i.e. $CEMI_4$. Ei also uses $CEMI_{12}$, not in the regulation, but to find indication of bad quality, when select DSOs which should be subject to extra inspection.

C. Two categories of baselines used

The basis for the benchmarking method is that the CoS for each DSO is compared to the CoS of other DSOs with similar conditions. Ei has chosen to use customer density, defined as the number of customers per km line, to represent the conditions under which the DSOs operate. The basic idea is that the baseline is calculated so that DSOs with the same customer density will get the same baseline. However, in order to incentivize those DSOs that already have a high level of CoS to maintain their level, separate baselines are calculated for over- and underperforming DSOs, as shown in Fig. 2.

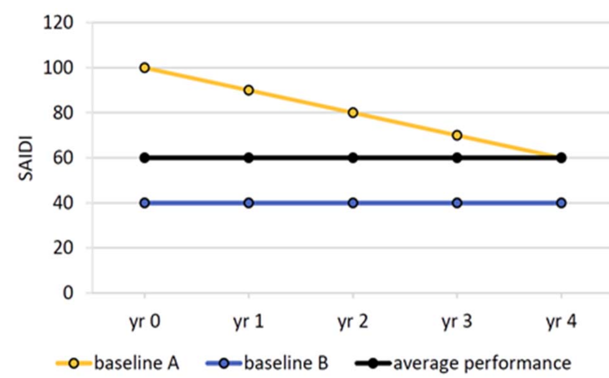

Figure 2 Examples of baselines for an underperforming network (baseline A) and an over-performing network (baseline B) respectively.

Over-performing DSOs will get their historical level as their baseline, exemplified as baseline B. The reason for that is that the customers in the area of the over-performing DSO already have paid for the current network and the associated level of CoS through their historical network charge, and the DSO should not be further rewarded for that.

For underperforming networks, the baseline is implemented periodically as for baseline A. Year 0 represents the baseline based on the interruption levels of the DSOs during the years 2010-2013, and year 1-4 represents the baseline of each year of the regulatory period. The reason for the periodization is that improvements of CoS often takes time, and that the DSOs should have a baseline that is reachable. A baseline is calculated separately for SAIDI and SAIFI, for notified and unnotified interruptions and for each customer group, which gives in total 20 different baselines for each DSO.

To find a baseline for the average performance, the DSOs need to be benchmarked. Historically, the distribution conditions based on customer density is divided into three categories; rural grid, mixed grid and urban grid with 0-10, 10-

20 and >20 customers per km line respectively. In reality, the prerequisites vary without such steps depending on the customer density, which should be reflected in the regulation. Thus, the average performance that is further used for setting the baselines for each DSO, vary depending on the customer density as exemplified in Fig. 3. DSOs located above the average performance line will get a baseline as baseline A in Fig. 2 , and DSOs located below the average performance line will get a baseline based on their own historical performance (baseline B in Fig. 2).The average performance is given by an equation of the type as in (4)

$$Y = \alpha + \frac{\beta}{T+\gamma} \tag{4}$$

where Y is the baseline, i.e. the average performance, given as notified and unnotified SAIDI and SAIFI respectively, T is the customer density (customers/km) and α, β and γ are parameters identified by making a least square fit of the baseline to the individual network performances. If the baseline is going to be useful, a sufficient number of DSOs needs to be represented in the benchmarking. In Sweden there are approximately 170 DSOs, which makes the method suitable. The baseline is calculated based on the average values of the indicators of all DSOs during 2010-2013.

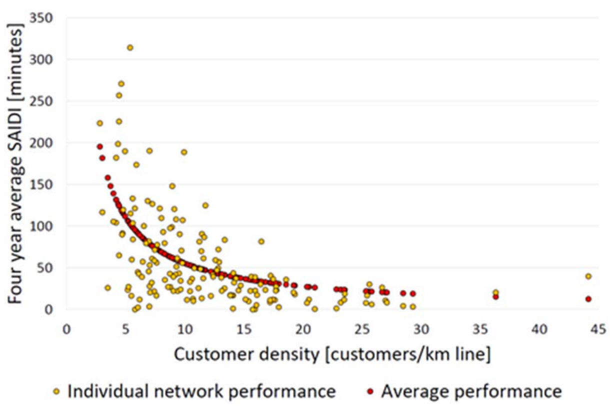

Figure 3 Continuity performance of the individual DSOs as a function of customer density in yellow and the average performance in red.

D. *Calculation of incentive*

When the interruption cost parameters are set, the baselines are calculated and the values for SAIDI, SAIFI and $CEMI_4$ are collected at the end of the regulatory period, it is time to calculate the total incentive, i.e. reward or penalty. The calculation of the total incentive is made in several steps. First, the yearly financial outcome, Q_y, based on SAIDI, SAIFI and the interruption costs are calculated as in (5)

$$Q_y = \sum_{k=1}^{5} \sum_{j=1}^{2} \Big(\big(SAIDI_{b,jk} - SAIDI_{o,jk}\big) K_{E,jk} + \big(SAIFI_{b,jk} - SAIFI_{o,jk}\big) K_{P,jk} \Big) \cdot P_{av} \tag{5}$$

where y represent the year, k represents the five different customer groups (1-5), j represents the two categories of interruptions (notified or not), b represents the baseline and o represents the outcome during year y. *SAIDI* is the average interruption time given in hours and *SAIFI* is the average number of interruptions. K_E is the cost parameter given in SEK/kWh, K_P is the cost parameter given in SEK/kW and finally, P_{av} is the average yearly power usage, calculated in (6):

$$P_{av} = \frac{E_{y,k}}{H_y} \tag{6}$$

where E is the total energy consumption for each customer type k, year y and H_y is the number of hours during the year y.

When the incentive Q_y is calculated, the incentive will be adjusted depending on $CEMI_4$. The size of the yearly adjustment, $CEMI_{4\delta y}$, is calculated from the baseline based on each DSOs own historical performance $CEMI_{4,b}$ and yearly outcome $CEMI_{4,y}$ as in (7)

$$CEMI_{4\delta,y} = CEMI_{4,b} - CEMI_{4,y} \tag{7}$$

To avoid unreasonably large impact of $CEMI_4$, a limitation is set to ±0,25 % of Q_y. If the total incentive Q_y is positive (i.e. addition on the revenue cap) and $CEMI_{4\delta y}$ is negative, the incentive will be reduced. If the total incentive Q_y is negative (i.e. reduction of the revenue cap) but $CEMI_{4\delta y}$ increased, the reduction of the incentive will be reduced. If Q_y is positive and $CEMI_{4\delta y}$ is positive, or if Q_y is negative and $CEMI_{4\delta y}$ is negative, the incentive will be unchanged. In this way, $CEMI_4$ is only used to mitigate the incentive and cannot make it larger. For the cases where $CEMI_4$ does not impact the incentive, the final yearly incentive Q_{Ty} is equal to Q_y. For the cases where $CEMI_4$ impact the incentive, Q_{Ty} is calculated by (8)

$$Q_{Ty} = Q_y\big(1 - \left|CEMI_{4\delta,y}\right|\big). \tag{8}$$

The total incentive for the four year regulatory period Q_T is finally summarized as in (9)

$$Q_T = \sum Q_{Ty} \tag{9}$$

E. *Limitation of incentive*

During the first period of regulation 2012-2015, the financial penalty or reward for the DSO was multiplied with a factor 0.5. However, if the objective of the regulation is to strive towards the optimal socioeconomic level of CoS, the marginal cost for increasing the reliability for the DSOs should be equal to the marginal cost for interruptions for the customers [11][16]. On the basis of this reasoning, the factor in the second regulatory period is set to 1.

If the relation between penalties or rewards and customer interruption costs are correct, the system would end up self-regulating [11]. However, studies dealing with customer interruption costs are always associated with a certain level of uncertainty. That motivates a limitation of the incentive to an upper and lower level. An upper cap of the incentive may also counteract an unmotivated high level of CoS, and a lower cap may protect the DSOs against too large economic loss for example as a result of a major weather event causing interruptions in a wide geographical area.

According to the Electricity Act, the total incentive for CoS in combination with the incentive for efficient utilization of the grid [8] should be limited to not exceed the return on the capital base. Prior to the second regulatory period, an analysis was made regarding the DSOs' financial return in order to determine a reasonable limit [4]. The analysis showed that it should be limited to not exceed ± 5 % of the revenue cap (was ± 3 % during 2012-2015).

IV. Incentives for Higher System Levels

The regulation of the CoS for the sub-transmission networks is designed in a slightly different way compared to the regulation of the DSOs described in chapter IV. The indicators used are Energy not supplied (ENS) and Power not supplied (PNS). ENS is calculated based on, P_{av}, as defined in (6) multiplied by total interruption time given in hours. PNS is calculated as P_{av} multiplied with total number of interruptions. Both ENS and PNS is calculated separately for each interconnection point or costumer and thereafter summarized. The interruption cost parameters [kSEK/kWh] and [kSEK/kW] is the same as for local DSOs. $CEMI_n$ is not included.

As for local DSOs, different regional DSOs have different prerequisites, but since the numbers of companies are few (around five in Sweden), it is not possible to calculate a general baselines as for the local DSOs. Instead, the historical levels of each company is used as the baseline. The baseline is calculated as the average value of the indicators for four years occurring six - two years before the regulatory period. The indicators ENS and PNS are calculated separately for different customer groups (same as for local DSOs) and for notified and unnotified interruptions. For regional networks, a lot of the interconnection points are connections to the distribution networks. The cost parameter used for those delivery points are an average national cost parameter, to represent a composition of different customer groups in the underlying network.

The incentives provided to the TSO are designed in a similar way as the incentives provided to the regional network operators. The same indicators are used, but since there are very few interruptions at transmission level, the baseline is based on data from a period of 10 years. Another difference is that the indicators PNS and ENS are based on the actual power and energy not supplied, and not the yearly average.

V. Conclusion

This paper describes the incentive scheme for CoS that is implemented as a part of the Swedish revenue cap regulation for the regulatory period 2016-2019. The incentive scheme has been developed to meet the objectives described in chapter III. The costs for interruptions are more closely tied to the societal costs by the differentiation into different customer groups.

The regulation incentivizes a higher level of CoS by comparing the indicators during the regulatory period to a baseline defined using the historical average performance benchmarked across all DSOs. The DSOs that already have a high continuity of supply is incentivized to maintain that level by calculating separate baselines for over-performing and underperforming DSOs. The regulation gives incentive to discourage unreasonable differences in CoS between networks by considering the customer density when the baseline is set for each DSO. Finally, the regulation gives incentive to discourage unreasonable large differences regarding CoS within networks by introducing the new indicator $CEMI_n$ that modifies the penalty or reward depending on if the indicator has improved or worsened. Thereby, the objectives of the regulation are met.

The outcome of this regulation will be followed up by Ei. Ei will also follow the development of incentive schemes for CoS in other countries, and aims to further develop and improve the method if needed for the coming regulatory periods. In the developing work, Ei currently uses a reference group of researches and also follow the research regarding develop more accurate interruption costs. Furthermore this paper act as reference material and inspiration to others as well as a chance for Ei to receive feedback valuable for future development.

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