

Incentive Scheme for Efficient Utilization of Electricity Network in Sweden

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Abstract—As a result of the 2012 Energy Efficiency Directive, the Swedish regulatory authority for energy, the Swedish Energy Markets Inspectorate (Ei), has introduced new rules regarding an efficient utilization of the electric power system. To incentivize distribution system operators (DSOs) to operate their networks in an efficient way, Ei has developed financial incentives within its revenue cap regulation.

This paper describes the newly developed incentive scheme in Sweden that aims to incentivize DSOs to a more efficient utilization of power systems; first implemented during the regulatory period 2016-2019. The indicators that are used for measuring to what extent the grid is utilized efficiently are: network losses, cost of the feeding grid and average load factor. 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—incentive based regulation, network losses, load factor, efficient power grid utilization.

I. INTRODUCTION

The distribution of electricity is considered as a natural monopoly in contrast to the electricity market that was deregulated 1996 in Sweden. Due to the lack of competition, distribution system operators (DSOs) are subject to regulation to promote efficiency and quality of supply and to ensure fair prices for customers. Electricity distribution tariffs shall, according to the Swedish Electricity Act [1], be reasonable, objective and non-discriminatory. There are currently approximately 170 DSOs in Sweden.

Ex-ante regulation of electricity network tariffs 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 DSO for a period of four years at a time. The revenue cap indicates the total amount that the DSO may charge their customers. The purpose of the revenue cap is that DSOs shall obtain reasonable coverage for their costs and reasonable return on the invested capital. Besides this regulation there are additional laws that gives

incentives to DSO such as requirement that no outages should be above 24 hours and individual customer compensation for outages above 12 hours see e.g. [2]. Furthermore, Ei has specified that no customer should have more than 11 outages per year.

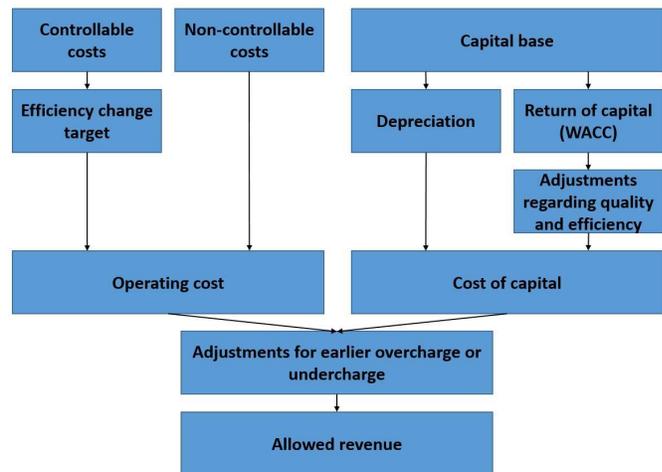


Figure 1. Components in the Swedish revenue cap regulation.

The revenue cap, whose components are illustrated in Fig. 1, is calculated as the sum of operational- and capital costs, with an adjustment for continuity of supply and efficiency in the grid utilization. The operational costs are divided based on what is considered a controllable or non-controllable cost. Operational costs that are considered controllable are based on the historical costs for each DSO and for which an efficiency requirement of at least one percent is applied for every year in the regulatory period. Operational costs that are considered as non-controllable are traditionally handled as pass through costs. However, some of them are not always 100 % “non-controllable” and can be adjusted due to the new regulatory parts introduced in this paper. These costs include e.g. charges for connecting to the sub-transmission level and losses.

The capital cost is calculated based on a list of standard costs provided by Ei, where the cost is asset based and valued based on existing infrastructure. The list includes the most common infrastructure components used by DSOs. The valuation of the infrastructure is accounting for the depreciation period (40 years for current carrying equipment and 10 years for other, e.g. meters and IT) and a weighted average cost of capital (WACC), which is then used to calculate the capital cost. The capital cost thus consists of a reduction in infrastructure value (real linear method) and a return on investments.

In the Swedish revenue cap regulation there is an adjustment of the revenue cap for continuity of supply (described in another paper [3]) and efficiency in the grid utilization; the latter is newly introduced and is presented in this paper. More detailed description is provided in a Swedish report [4] which treats the subject more thoroughly. The incentive scheme is designed in such a way that a potential adjustment of a DSO's revenue cap is limited so that the size of the addition or reduction regarding efficiency plus continuity of supply cannot exceed 5 % of the revenue cap.

II. BACKGROUND

The 2012 Energy Efficiency Directive (EED) [5] established a set of binding measures to help EU reach its 20 % energy efficiency target by 2020. Under the Directive, all EU member states are required to increase energy efficiency at all stages: from production to final consumption. EU member states were required to transpose the Directive's provisions into their national laws by June 5th, 2014.

Pursuant to Article 15(4) of the EED, Member States shall ensure that DSOs are incentivized to improve efficiency in infrastructure design and operation. This was implemented in Sweden by introducing new rules in the Swedish Electricity Act. When calculating the revenue cap, Ei shall take into account to what extent the operations are conducted in a manner consistent with or contributing to an efficient utilization of the power grid. Such an assessment may result in an increase or decrease in what is considered to be a reasonable rate of return on the capital base [6].

As a result of the new rules, Ei was given the mandate to decide on what is considered as an efficient utilization of the power grid, and to design the new incentive scheme. In doing this, Ei had to account for the changes that are to come in the energy market. The major challenge is to shift the current market so that supply and demand mutually optimize the system and adapt to grid capacity shortage.

III. INCENTIVE SCHEME FOR EFFICIENT GRID UTILIZATION

The objective is that the regulation should be technology-neutral and that it should focus on functionality requirements, rather than detailed regulation on how the functionality should be achieved. Technology-neutrality means that the regulator does not regulate the choice of technology, instead the goal is that the DSOs and the market make the choice of technology. Since the focus is on functionality requirements and quality – the output of the regulation – these parts of regulation is often referred to as an output regulation.

One of the incentive schemes applied in the Swedish regulation of DSOs aims to increase the efficiency of the grid utilization. The two indicators that are used for measuring to what extent the grid is utilized efficiently are (a) network losses and (b) the cost of feeding grid and average load factor. These two indicators aims to incentivize DSOs to operate their networks in a way that promotes energy efficiency. Economic incentives for DSOs are thus created to lower network losses and to reward peak shaving.

A. Network losses

Network losses in the distribution of electricity are defined as the difference between the amount of energy that is fed into the grid and the amount of energy that is consumed or exported, i.e. taken out of the grid.

Ei has chosen to use network losses as an indicator for an efficient utilization of the power grid. The reason for this is that network losses have a direct impact on network costs and energy consumption. An incentive for DSOs to reduce the network losses therefore creates clear benefits for network users and for the society.

As network losses are dependent on the power flow, the indicator need to be normalized with respect to the total amount of energy distributed in the grid. Without the normalization, a decrease of network losses can be the result of e.g. warm weather, and not a more efficient grid utilization. The indicator that is used to create an incentive to reduce network losses during the regulatory period is thus the proportion of network losses in relation to the total amount of energy distributed in the grid. The incentive is designed so that an increase or reduction of the percentage of network losses in comparison to the DSO's historical level of network losses will lead to a reduction or addition to the revenue cap. Equation (1) is used to calculate that incentive:

$$K_n = (Nf_{norm} - Nf_{turn-out}) \times E_{turn-out} \times P_n \times 0.5 \quad (1)$$

Where:

- K_n [kSEK] (thousands of Swedish kronor) = The value of the incentive for network losses, an addition or reduction on the revenue cap.
- Nf_{norm} [%] = The historical share of network losses for each DSO (2010-2013) as a percentage of the total amount of energy distributed.
- $Nf_{turn-out}$ [%] = The share of network losses for each DSO during the regulatory period (2016-2019) as a percentage of the total amount of energy distributed.
- $E_{turn-out}$ [MWh] = The amount of distributed energy during the regulatory period (2016-2019).
- P_n [kSEK/MWh] = Price per megawatt hour for network losses calculated as an average price during the regulatory period (2016-2019). All DSOs' costs for network losses are considered in the calculation.

The factor, 0.5, in (1) leads to the fact that an improvement regarding network losses will reward the DSOs with half of the additional value and the other half of the additional value will be transferred to the customers due to a lower revenue cap. On the contrary, if the share of network losses increases, half of the reduction of the revenue cap will be transferred to

the customers from the DSO's revenue cap. This can be seen as a limitation on the incentive regarding network losses.

Distributed energy production can contribute to either increasing or decreasing network losses. If the share of network losses increase due to increased local production, the reduction can be limited depending on what is considered reasonable in the view of how much impact the local production has had on the network losses. This exception is introduced so that the incentive not inhibits the expansion of distributed local energy production.

B. Cost of feeding grid and average load factor

An efficient utilization of the power grid can be achieved by load mitigation and by peak load shaving. If this is done, the available capacity of the grid increases, which can allow for the connection of more renewable energy or more customers without having to invest in more capacity. A more even load also reduces the power losses and reduces costs for feeding grids.

The indicator implemented to incentivize DSOs to adjust the load in the distribution grid is the load factor in the interconnection points between the DSO and the superior grid. The load factor is defined as the ratio of average load and maximum load. During occasional power spikes and at times when there are large variations in the load, the load factor will be low. A high load factor, however, shows that the load curve variation is not as big and that the system is utilized more efficiently, which is benign both technically and economically.

In order to monetize the incentive, Ei combined the load factor with the reduction of the cost that DSOs pay for withdrawal of electricity. Whilst the incentive to lower network losses can result in both an addition and a reduction of the revenue cap, the incentive related to the load factor is solely a reward scheme. Equation (2) is used to calculate the incentive for cost of feeding grid and average load factor.

$$K_b = L_{f_{turn-out}} \times B_{diff} \times E_{turn-out} \quad (2)$$

Where:

- K_b [kSEK] = The value of the incentive for cost of feeding grid and average load factor.
- $L_{f_{turn-out}} = (\sum L_{f_{day}}) / D_t$ = The sum of all daily load factors divided by the number of days during the regulatory period.
- $L_{f_{day}} = P_{average} / P_{max}$ = The average load divided by the maximum load during a day.
- $P_{average}$ [MW] = The average load during a day. This is calculated as the sum of load in the interconnection points between DSOs during a day divided by 24 hours.
- P_{max} [MW] = The maximum load during a day. This is calculated as the sum of load in all interconnection points at the hour of the day when the highest load sum occur. This calculation presume that the load measurement is made on an hourly basis.
- B_{diff} [kSEK/MWh] = $B_{norm} - B_{turn-out}$ = The saving per megawatt hour for the cost that DSOs pay to the higher voltage grid, i.e. the feeding grid charge, for the withdrawal and costs for the input of electricity.

- B_{norm} [kSEK/MWh] = The cost that DSOs pay to the higher voltage grid, i.e. the feeding grid charge during the reference period (2010-2013) divided by the amount of distributed energy during the reference period.
- $B_{turn-out}$ [kSEK/MWh] = The cost that DSOs pay to the higher voltage grid, i.e. the feeding grid charge, for the withdrawal and costs for the input of electricity during the regulatory period (2016-2019) divided by the amount of distributed energy during the regulatory period.
- $E_{turn-out}$ [MWh] = The distributed energy during the regulatory period (2016-2019).

In the incentive for cost of feeding grid and average load factor, there is no fixed factor for what share of the addition to the revenue cap that the DSO may keep, compared to the factor 0.5 for the incentive regarding network losses. In this case, the DSO first need to make an improvement regarding the cost for the feeding grid and that amount will be shared between the DSO and its customers. The percentage that the DSO may keep corresponds to the load factor, which in the extreme case where the average load and maximum load are the same results in the company keeping the whole profit.

IV. HISTORICAL STATE

A. Network losses

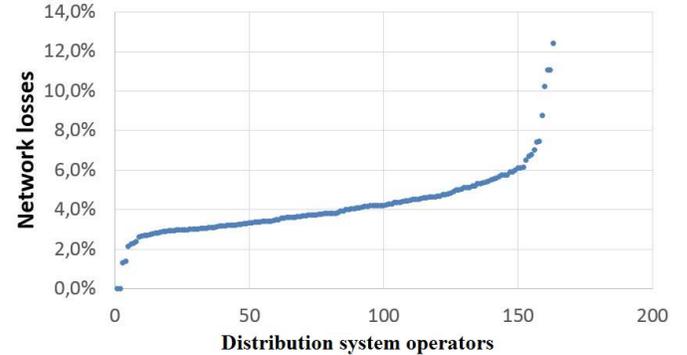


Figure 2. The share of network losses for Swedish DSOs in 2012.

The share of network losses for Swedish DSOs in year 2012 is illustrated in Fig. 2. A majority of Swedish DSOs had network losses in the interval three to six percent of total amount of energy distributed. Only a small number of DSOs experienced network losses exceeding ten percent since 2006.

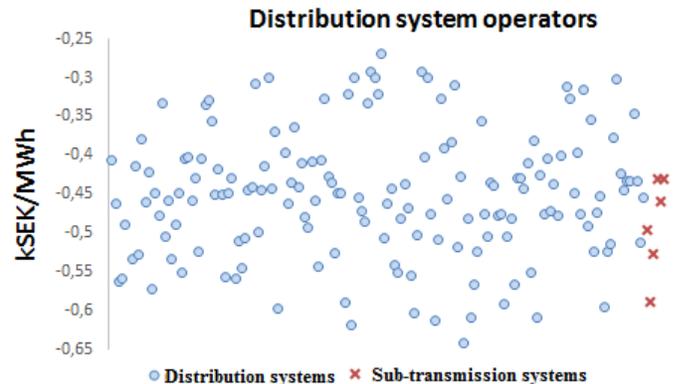


Figure 3. The cost of network losses for Swedish DSOs in 2012.

The cost of network losses for Swedish DSOs in 2012 is illustrated in Fig. 3. The blue circles represent DSOs at local level and the red crosses represent DSOs on the sub-transmission level. Two DSOs had a cost just below 0.20 kSEK/MWh and one had a cost at almost 1.2 kSEK/MWh. These three extremes are excluded in the figure. The other have costs between 0.25 and 0.65 kSEK/MWh. The Swedish TSO is not included in the figure. Ei choose the average cost of the different DSOs' costs for network losses when calculating the incentive. The reason for this is to consider all forms of purchase types and prices, which differ among the DSOs.

B. Cost of feeding grid and average load factor

A real example of the fluctuation of the daily load factor is illustrated in Fig. 4. The daily variation of the load factor naturally differs among different DSOs and can, as presented, cover a big range over a period of one month. The load factor in Fig. 4 is a visualization of data from a small DSO with a high percentage of local production.

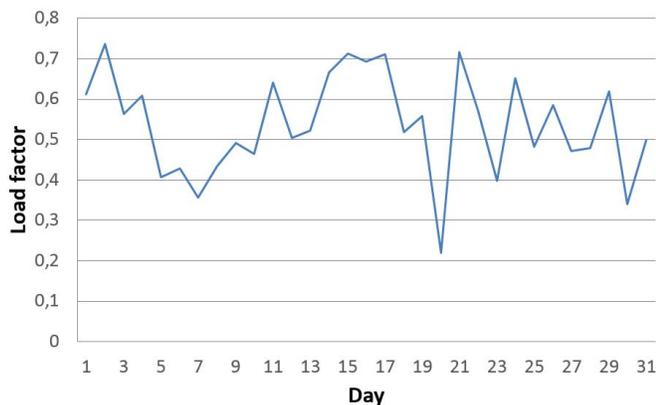


Figure 4. Example of a real daily load factor.

The cost for feeding grid as a share of distributed energy for Swedish DSOs in 2012 is illustrated in Fig. 5. The blue circles represent DSOs and the red lines represent DSOs on the sub-transmission level. The Swedish TSO is not included.

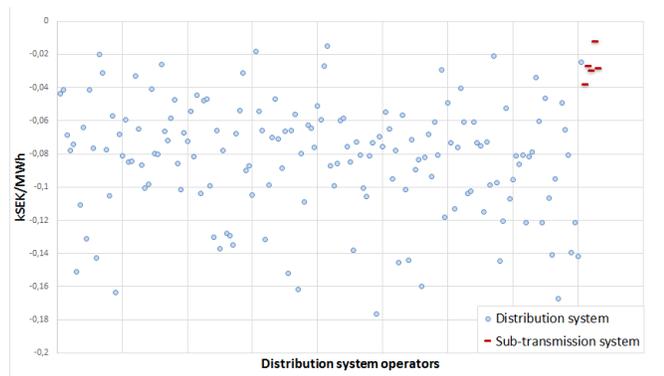


Figure 5. The cost for feeding grid as a share of distributed energy for Swedish DSOs in 2012.

V. CONSEQUENCES

In order for the DSOs to increase their revenue caps an active approach has to be taken. The goal with the new

incentives regarding efficiency in the grid utilization is to incentivize the DSOs to strive towards efficiency as established by the EED. If improvements in the efficiency of the grid utilization is made, it will favor both the DSOs, their customers and the market as a whole. The regulation adjustment for efficiency in the grid utilization could in the long run lead to a higher share of energy efficient components in the market, which further could lead to a development for such products and their market.

A. Network losses

There are several reasons to why network losses arise and some parts of the network losses are inevitable. The share of network losses that can be reduced therefore naturally differ among DSOs due to, for example, different customer density and cable lengths. This is the reason why the incentive is calculated based on historical values for each specific DSO, which will account for the individual company's circumstances assuming they existed in the past.

Possible measures to reduce the share of network losses include investing in smarter and better technology, for example power lines and transformers with less losses than those who are currently used, or using technical inventions such as Volt-VAR Optimization (VVO), which provides real-time information and continuous optimization of the voltage which aims to minimize network losses and the load.

The incentive regarding network losses has a potential for promoting efficiency. In a calculation that assumes that all DSOs with network losses of more than four percent would cut their network losses down to four percent, a yearly energy saving of 374 gigawatt hours would be made. This would result in a social profit of approximately 173 million Swedish kronor per year (≈ 18.2 Euro April 2016). These 173 million would be divided equally among the DSOs and their customers, which means that 86.5 million goes to the DSOs as higher profit and the remaining 86.5 million goes to the customers through lower tariffs. Over a regulatory period of four years a saving of almost 1.5 terawatt hours can be made, which corresponds to a profit of almost 700 million Swedish kronor for the DSOs and their customers to share.

B. Cost of feeding grid and average load factor

In order for the DSOs to lower the cost to their feeding grid as a result of an improved average load factor, a shift in the energy consumption of their customers' needs to be made. This means that the DSOs can improve the revenue cap by forwarding incentives to their customers to reward peak shaving.

Currently, there are few or no incentives for customers to adapt their energy consumption to the total load system level as their tariffs usually do not depend on the demand and the capacity of the network. A possible way to improve the load factor is thus to implement network tariffs that vary based on the real output in the network, which can incentivize the customers to even out their energy consumption over time. To further incentivize the customers to perform peak shaving, DSOs can design the tariffs in such a way that it will cost more for the customers to withdraw electricity from the grid

during the hours of the day where the load is high and less when the load is low.

A previous study [7] investigating the results of demand response and load shifting from peak to off peak hours shows the possibility of monetary savings for both the DSOs and their customers. The analysis led to the conclusion that flexible capacity based tariffs is a good approach to stimulate a DSO's customers to manage their load.

C. *The accompanying cost of the introduced incentive regulation*

The incentive scheme regarding network losses will not cause any new administrative costs for the DSOs. The data necessary to calculate the incentive rate is already reported to Ei on a yearly basis. How the DSOs will respond to the incentive is difficult to predict and the potential costs to respond to the incentive greatly depends on the measures the companies choose to implement. The incentive is designed in such a way that it identifies the improvement the DSOs should strive to make, but the methods to carry out this is up to each DSO. The cost for the customers, based on the incentive regarding network losses, depends on the response of their DSO since they share the potential reward or penalty.

The incentive scheme regarding the cost to the feeding grid and average load factor will lead to some additional administrative costs for the DSOs. This is a consequence of the fact that they will have to report their load factor to Ei. The cost will increase depending on the number of interconnection points within a DSO's network, but for larger DSOs with more interconnection points the work can be automatized and the total costs are estimated to be fairly low. For both DSOs and their customers the incentive regarding the cost to the feeding grid and average load factor will require an effort to cooperate in changing consumer's behavior regarding how and when they consume electricity.

VI. CONCLUSIONS AND WAY FORWARD

In general, the share of network losses, the cost of feeding grid and average load factors differs quite a lot between different DSOs. Furthermore those parts have traditionally been seen as non-controllable in the regulation, i.e. changes that lead to changed costs has been totally covered by customer tariffs. Now they can be adjusted and hence the DSOs have more direct incentives to improve the utilization.

This paper aims to act as reference material and inspiration to others as well as a chance for Ei to receive valuable feedback for future developments. The regulatory period, 2016-2019, is now ongoing and the consequences of the implemented incentive scheme is yet to be seen. Ei will monitor the performance of the DSOs during the regulatory period in order to see the results of the new incentive scheme. For regulatory periods to come, Ei aims to investigate the possibilities to further develop the means to incentivize an efficient utilization of the power grid. In the developing work, Ei currently uses a reference group of researches.

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