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Abstract: This study provides a summary on how Swedish distribution system operators (DSO) are regulated after a revenue cap model, and describes a potential development on the current utilization incentive scheme within this regulation. The analyses are based on data from a Swedish DSO, which have been elaborated with the use of demand response program. The outcome of the demand response simulation has in a later step been applied to calculate the incentive in the revenue cap regulation. Two different calculation approaches are used and compared in order to calculate the load factor in the revenue cap regulation. The results of the case study show that by applying a weighted daily load factor, the DSO in the case study can receive ~3% additional economic income compared to applying an average daily load factor in the incentive calculation. The motivation behind applying weighted load factor is to prioritize days with high energy consumption since those days have more impact on the costs. Most important, the analysis display that replacing the average load factor with a weighted load factor have a non-negligible impact on the incentive calculation and hence if the change fulfill its purpose enough.

1 Introduction

The entire energy market in Sweden, specifically the monopoly part of market, is under substantial transformation and shifting towards improving the efficiency of infrastructure design and operation. The explanation of the transformation can be explained in greater environmental awareness and due to EU's request of pursuing 20% energy saving by 2020. To meet this target, a set of mandatory measures, called the Energy Efficiency Directive, were established in 2012 [1]. According to the Directive, all EU countries should improve the energy efficiency of all energy-related processes, ranging from energy production to its final consumption [1].

As a result of these directives, the Swedish national regulatory authority (NRA) for energy; named the Swedish Energy Market Inspectorate (Ei), introduced new incentives schemes for efficient utilisation of electricity distribution. The efficient utilisation incentive scheme is integrated in the regulation that determines revenue caps of all distribution system operators (DSOs). One of two imposed incentives focuses on improving the load factor and reducing the costs for feeding the grid. A deeper description of the regulation framework and the incentives of efficient utilisation are described in Section 2. The reason to enforce incentives in the regulation framework is to drive to streamline desirable levels of DSOs' network performance [1], which at the same time gives the DSO the opportunity to maximise financial profit by improving its utilisation performance.

1.1 Purpose of the study

On behalf of the Energy Market Inspectorate, a master thesis [2] was performed with the purpose of investigating potential indicators for efficient utilisation, which could later be used in the incentive framework. The result of the study encourages and discusses a recommendation to implement a change in today's calculation of the load factor used in the regulation. Instead of using a load factor calculation based on the average of all daily values, a weighted load factor calculation should be implemented to prioritise days with higher demand energy.

The use of the weighted load factor in the incentive scheme has never been fully analysed. From a regulatory point of view, it is important to investigate and evaluate the outcome of using a weighted load factor in the incentive scheme before considering such change. The development work should consider whether the method qualifies for the given directives for efficient utilisation and it is also good to maintain a robust regulation over time to avoid too much uncertainty for the DSOs if possible (i.e. only implement well motivated changes).

This paper is based on a study performed at KTH Royal Institute of Technology in Stockholm in collaboration with the Swedish NRA Ei. The paper discusses and analyses the current incentive scheme of efficient utilisation and concludes whether it is motivated or not to make any developments in incentives to increase system utilisation by improving load factor calculation for coming regulatory period (2020–2023). One way to evaluate the efficient utilisation incentives is to apply demand response (DR) programme in order to fulfil the request of efficient utilisation. DR programmes have in recent years been highlighted in the electricity market due its success in providing substantial improvements in efficient utilisation [3] by balancing customer's demand of electricity with the supply of electricity. Despite that DR programmes are sufficiently well regarded [3], it has not fully been emerged in Sweden. It is the NRA's role to evaluate incentives that are objective and fair (but technology neutral). Then other parties should decide to implement solutions, such as DR, that corresponds to those incentives.

This paper begins with an outline of the regulatory framework, emphasising on the incentives for efficient utilisation and a presentation of the calculation approaches for quantifying the load factor. The methods in this case study are: (i) arithmetic mean, which is the mean value of the daily load factors for a defined time period. (ii) Weighted load factor, a function that prioritise the days with higher energy usage under the defined time period. To evaluate the effectiveness of the two methods, time-of-use (TOU) [4] programme, which is one price-based DR programme that is constructed after fixed tariff rates in the electricity price, is applied in order to respond to efficient utilisation and obtain improvement in the load profile. The results from the DR implementation are meant to measure the technical effects, which in the end are applied in the incentive regulation in order to quantify the financial outcome of the incentives. Based on the results, the methods of calculating the load factor are compared, and then motivated which method is the most applicable in the incentive regulation in order to fulfil the requirement of efficient utilisation.

2 2016–2019 revenue cap regulation

The regulation framework of power systems has been under significant change over the last 12 years. In 2012 the NRA introduced an ex ante revenue cap regulation, which covers a period of 4 years. For the regulatory period 2016–2019, the revenue framework was modified mainly by imposing new ways of calculating capital costs and performance incentives in order to stimulate the network of the power system towards the so-called smart grid paradigm. Fig. 1 depicts the current revenue frame work, shown in its full shape. For more details of the regulation, see [5].

2.1 Indicators for quantifying the incentives of efficient utilisation

One of the key changes between the previous and the current regulatory period is the imposition of incentives for efficient utilisation. The utilisation incentives is currently divided into two parts which focus on: (i) increasing system utilisation by reducing the energy losses and (ii) incentive to adjust the load profile by optimising load factor and reducing the cost to the feeding grid. The calculations of the incentives are given by (1) and (2), where (1) calculates the financial outcome of the energy losses (K_n) and

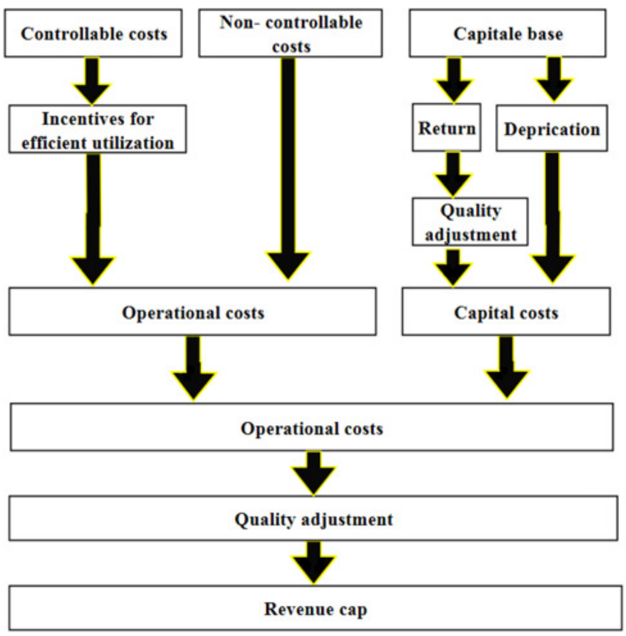

Fig. 1 *Flowchart of the revenue cap regulation for the 2016–2019 regulatory period*

(2) calculates the incentive for load factor and cost of feeding the grid (K_1)

$$K_n = \left(\mathrm{N\,f}_{\mathrm{Norm}} - \mathrm{N\,f}_{\mathrm{Outcome}}\right)E_{\mathrm{tot}}^{\mathrm{Outcome}} \times P \times 0.5 \qquad (1)$$

$$K_1 = \begin{cases} 0 & \text{if } C_{\mathrm{SN}}^{\mathrm{Norm}} < C_{\mathrm{SN}}^{\mathrm{Outcome}}, \\ \text{else} & \mathrm{L\,f}_{\mathrm{Outcome}}\left(C_{\mathrm{SN}}^{\mathrm{Norm}} - C_{\mathrm{SN}}^{\mathrm{Outcome}}\right)E_{\mathrm{tot}}^{\mathrm{Outcome}} \end{cases} \qquad (2)$$

where $\mathrm{Nf}_{\mathrm{Norm}}$ (%) addresses the baseline of the network losses and $\mathrm{Nf}_{\mathrm{Outcome}}$ (%) addresses the outcome of the network losses and P represents the cost for network losses (SEK/MWh). $\mathrm{Lf}_{\mathrm{outcome}}$ is the outcome of the load factor (defined in the following section), $E_{\mathrm{tot}}^{\mathrm{Outcome}}$ represents the outcome of the total annual energy usage (MWh), $C_{\mathrm{SN}}^{\mathrm{Norm}}$ (SEK/MWh) represents the baseline of costs for the feeding grid and $C_{\mathrm{SN}}^{\mathrm{Outcome}}$ (SEK/MWh) represents the outcome cost for the feeding grid. By summarising the incentives together, (1) and (2) gives the total value of the utilisation incentive. The sum of this utilisation incentive scheme together with a continuity of supply incentive scheme (described in e.g. [5, 6]) can only affect ±5% of the total revenue cap.

2.2 Load factor calculation method approaches

Here, the load factor refers to a rate regarding the efficiency of energy usage. The definition of a load factor is based on a daily rate, which is quantified by including average value of electrical demand through the day, dividing by the peak value of energy usage that day. The definition of the load factor is obtained as

$$\mathrm{L\,f}_{\mathrm{day}} = \frac{\mathrm{Average}(E_1 + E_2 + E_3 + \cdots + E_{24})}{\mathrm{Max}(E_1 + E_2 + E_3 + \cdots + E_{24})} \qquad (3)$$

where E is the hourly load in MW and E_i refers to energy consumption during hour i of the day ($i = 1$–24). A high utilisation rate indicates a good system performance.

Since the revenue framework and the incentive regulation are adapted after a longer time period, the quantification of the load factor is calculated based on all days load during that period. In this paper, these methods of calculating the load factor used in the regulation will be analysed and evaluated. This to highlight the one which is more suitable and effective in the incentive framework. To evaluate and select appropriate method, these two load factor approaches are argued in this paper.

2.2.1 Calculation method 1 – average load factor: The load factor that E_i currently apply in the quantification of the incentives for load is using an average value of all daily load factors. An average load factor calculation responds to the following equation:

$$\mathrm{Lf\_}E_{i\,\mathrm{Outcome}} = \mathrm{Aver}(\mathrm{L\,f}_1 + \cdots + \mathrm{L\,f}_j + \cdots + \mathrm{L\,f}_{D_N}) \qquad (4)$$

where $\mathrm{Lf\_}E_{i\mathrm{Outcome}}$ is the average load factor ratio based on total amount of daily load factors during the regulatory period, Lf_j is the daily load factor during day j based on the formula from (4); D_N refers to the total number of days during regulatory period. In this study D_N covers 365 days.

2.2.2 Calculation method 2 – weighted load factor: This case is based on a previous study from [2] which suggests to develop and upgrade the current load factor calculation that is used to compute the incentive given for improving the load factor and cost of grid feeding, by imposing a weighted load factor calculation

$$\mathrm{Lf\_}U_{\mathrm{Outcome}} = \sum_{j=1}^{D_N}\left(\frac{E_j^x}{\sum_{j=1}^{D_N} E_j^x}\right)\mathrm{Lf} \qquad (5)$$

where Lf_f the same as in (4) is, D_N refers to the total number of days during regulatory period. In this study D_N is as defined in method 1 (i.e. 365 days), x is an exponential function for E, a weighting factor which could be defined from 0 up to infinity. The higher the x value the more important are the days with higher energy usage, days with lower energy usage matter less. If $x=0$, (5) is equal to (4), if $x=1$ there is a linear weight (i.e. double as much energy → double as much weight) and $x=\infty$ gives only the day with highest energy matters. In this case study, $x=2$ (a day with doubled energy has a 4 times higher weight). However, more values of x will be evaluated than exemplified in this paper. Fig. 4 shows a first example of results testing more x values as a pre-study towards future work where the weighted load factor will be evaluated further.

3 Study of the calculation method approaches and the application

The results of this case study are based on a data from a medium-sized DSO in Sweden, which provides data regarding the total energy demand of 1400 residential customers during a year. The total energy usage and load pattern for all customers is displayed in Fig. 2.

To evaluate the effectiveness of the two methods in the incentive framework, a case study in the form of improved utilisation performance has to be performed.

3.1 Simulations with TOU programme

To achieve and demonstrate improved system performance by flattening the load profile, the input data is being modified by using the simulation tool MATLAB and TOU application, which is based on the mathematical formulation from [7]. The price

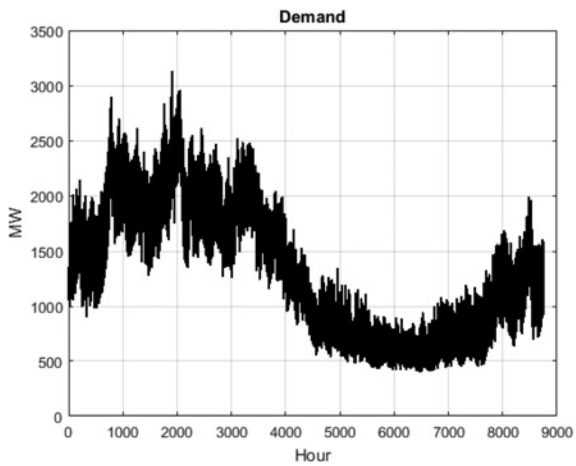

Fig. 2 *Overview of the initial load profile*

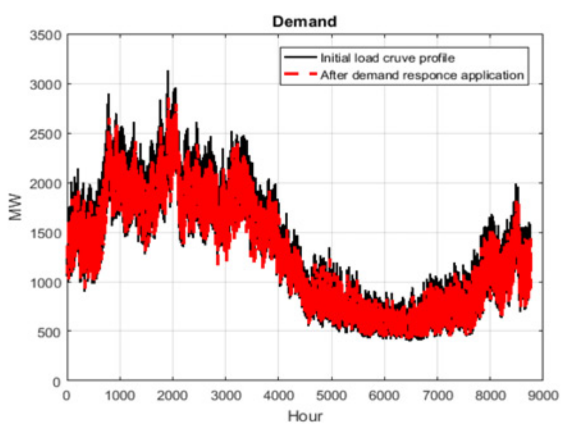

Fig. 3 *Two load profiles, the black curve is the initial load curve and the read load curve responds to power demand after implementing TOU*

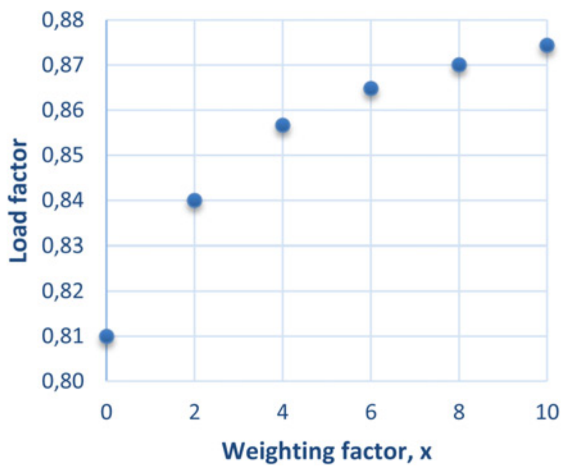

Fig. 4 *Load factor with different x*

elasticity, which is one of the key factors that controls and outlines TOU performance, has been given the value −0.007%. The value is based on the definition of the price elasticity for Swedish households from [8]. The flat price rates were considered as 232 SEK/MWh, which corresponds to ~24.4 EUR/MWh, during peak hours that take place between 16–23 O'clock, and 93 SEK/MWh = ~9.8 EUR/MWh, during the flat hours. The two price rates were determined after a project performed by Hawaiian Electric [9] and converted to Euros according to currency exchange rate in January 2017 [10].

TOU programme is of the one several DR programmes [11] and well-known in the smart grid application, due its recognition for successfully overcoming unflattering spikes and inflexible energy usage.

As shown in Fig. 3, the initial load profile from the DSO has been modified with TOU application in order to quantify and account the two defined calculation method approaches. Based on the result from the TOU performance, the two methods of calculating the load factor will be quantified and applied in the incentive calculation of load factor and cost of feeding the grid, in order to receive a demonstrative and a more measurable understanding of the two efficiency ratios and its effect on the incentive framework.

3.2 Quantifying future costs for the feeding grid

The cost for the feeding grid, after the improvements in the load profile, is determined after mathematical proportionality which can be obtained by using following equation:

$$C_{\mathrm{SN}}^{\mathrm{Outcome}} = \frac{C_{\mathrm{SN}}^{\mathrm{Norm}}\left(1 - \mathrm{L\,f}_{\mathrm{Outcome}}\right)}{\left(1 - \mathrm{L\,f}_{\mathrm{Norm}}\right)} \tag{6}$$

where $C_{\mathrm{SN}}^{\mathrm{Outcome}}$ is the cost of the feeding grid during the regulatory period, $C_{\mathrm{SN}}^{\mathrm{Norm}}$ is the historical cost for the feeding grid, $\mathrm{L\,f}_{\mathrm{Norm}}$ is the load factor from the previous regulatory period and finally $\mathrm{L\,f}_{\mathrm{Outcome}}$ is the load factor during the regulatory period. The historical costs are taken from NRAs norm lists. The data in Table 1 depicts the initial values of the indicators in this study.

Table 1 Initial value before TOU application

Variable	Initial value
energy usage	11 200 MW
network losses	4.19%
cost for superior network	7.52 EUR/MWh[a]
initial load factor	0.76[b]; 0.79[c]

a Based on the currency exchange 1 EUR ≃ 9.50 SEK [10].
b Load factor based on method 1.
c Load factor based on method 2.

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Table 2 Presents the results of the technical measurements, before and after adjustment in the load profile

Variable	Initial value	Outcome of DR
energy usage, MW	11 200	11 006
network losses, %	4.19	4.12
load factor – method 1	0.76	0.81
load factor – method 2	0.79	0.84

Table 3 Show the improvements in the cost of feeding the grid, the outcome of the costs is based on (7)

Method 1	Initial value, EUR/MWh[a]	Outcome of DR
feeding grid cost	7.52	5.91
method 2		
feeding grid cost	7.52	5.68

a Based on the currency exchange 1 EUR ≃ 9.50 SEK [10].

Table 4 Results of the incentive based on the two defined calculation methods of the load factor

Calculation approach	Bonus of the incentive, EUR
method 1	16,800[a]
method 2	17,400[a]

a Based on the currency exchange 1 EUR ≃ 9.50 SEK [10].

4 Results of the case study

The results of this case study contribute to the evaluation of two load factor calculation approaches. Different TOU application results have been put into incentive calculations. The economic outcome of improving the load factor and reducing cost for feeding the grid gives a more measurable dimension as in whole of the impact.

Fig. 3 displays the performance of an improved utilisation. The red curve illustrates the outcome in the load profile after TOU implementation and the black curve is the initial demand profile under a year that covers 8760 h. With this approach, the initial and improved system profile is presented in Table 2. As it is shown in the table, the load adjustment reduces total electrical demand of 200 MW and increase the load factor with 0.05 units in both methods.

The final step of this study is to investigate the economic outcome of the incentive of improving load factor and reducing the costs for feeding the grid. The economic outcome is not only based on technical measurements in each method, but also based on the difference in the cost of feeding the grid. The outcome of the feeding grid cost is based on (6). These costs are summarised in Table 3 for each method.

Finally, the entire bonus of the incentive of improving load factor and reducing the cost for feeding grid, for each case is summarised in Table 4.

5 Closure

5.1 Way forward for the NRA

One of the core obligations for the Swedish NRA is to determine the revenue cap for the DSO, which is based on DSO's system performance. In 2016, the regulatory framework was updated with imposing incentives of efficient utilisation. One of the incentives is aiming to improve the load factor and reduce the costs for feeding the grid. A previous work from [2], which is based on investigating the indicators of the incentive framework, gives the NRA the recommendation to impose a weighted load factor calculation approach instead of using the average load factor calculation. The outcome from the study gives the NRA input to its decision whether to adjust the load factor calculation for the coming regulatory period. Depending on the method, thus weighted or average load factor, applied in the incentive framework it can lead to a change in the revenue regulation and a discussion in performance utilisation, whether the NRA only wants to target efficient utilisation for the peak days or to target a balanced load profile in its hole.

5.2 Pre-study of testing more x values in the weighted load factor calculation approach

In this paper results from one specific distribution system has been presented exemplified by using $x = 2$ in the weighted calculation approach presented in (5). In Fig. 4 resulting load factors with more x values are shown. It is clear that the choice of x is important since it has significant impact. However, this is just an example and in this specific case, the higher the x, the higher (i.e. better) the load factor. It is however not possible to say that this always is the case just from a single example. In the exemplified system, days with lower energy usage involve a higher rate of power spikes and fluctuations, but other system can have other characteristics. In the end, the x value should be properly chosen thus to achieve balance in the load profile during days with high demand.

Most important, the analysis display that replacing the average load factor with a weighted load factor have a non-negligible impact in the incentive calculation and hence if the change fulfil its purpose enough, it can be motivated to have a more advanced equation than today.

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