IMPACTS OF DIFFERENT POWER-BASED DISTRIBUTION TARIFFS FOR CUSTOMERS

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ABSTRACT

Electricity distribution systems are facing changes since distributed energy resources, such as distributed generation (DG) and electric vehicles (EV), are becoming more common in the energy system. Load profiles of end-customers are changing from the energy incentive towards peak power intensive type. Decreasing trend of energy transfer in distribution is challenging the present energy-based tariff structure of distribution system operators (DSO). Due to capacity based dimensioning of electricity distribution system, the incentives to power-based customer tariffs are increasing. This paper focuses on studying how power-based tariffs with different parameter settings would affect the distribution of customer payments.

INTRODUCTION

Households’ electricity consumption patterns are changing since environmental awareness increased and concerns about climate change has aroused among the people. Energy saving solutions are spreading and at the same time fossil fuels are gradually superseded by renewable resources. Distributed electricity generation, such as rooftop solar photovoltaic systems (PV), are becoming more common, and thereby the mass production of solar panels has decreased the price, which encourages even more investments into PV systems [1]. Electric vehicles are also becoming an alternative for traditional fossil fuel based vehicles, which can be seen from the growth of volumes of plug-in electric vehicles annual sales [2]. From electricity grid’s point of view these changes mean, that momentary powers in the grids are rising and energy consumption is decreasing or at least not increasing as fast as power [3].

Furthermore, traditional energy-based pricing creates cross subsidies between customer groups. Distributed generation and energy saving appliances can reduce owners’ distribution bills, but since these actions do not reduce overall grid costs, DSOs have to collect reduced incomes from other customers by raising prices. In the Nordic conditions, these subsidies are significant since solar PV production occurs in the summertime whereas grid peak loads happen in the wintertime, when electric heating is used and PV production is not available. Fig. 1 shows a typical primary transformer level load curve in Finnish conditions.

In the first chapter, the background of the study is introduced. Followed by a short introduction into Nordic energy markets, then introduction to publications of power-based tariffs (PBT) and already implemented PBTs. After that assumptions made in this study are explained. In the second chapter, studied PBT models are explained and compared, and their effects are considered. The usage of different time periods with PBTs are considered.

Finally a case study is carried out with automatic meter reading (AMR) data of a medium size Finnish DSO.

Nordic energy markets

In the Nordic countries the electricity business has been differentiated so that customers can buy electricity from any electricity seller but have to pay transmission and distribution costs and electricity taxes to the local distribution system operator. DSOs’ costs are mainly fixed costs and mostly dependent on peak powers on their grids. In Finland, DSOs have had to install AMR meters for almost all customers. AMR meters register customers’ consumed hourly energies.

Traditionally, distribution tariffs have been energy based (€/kWh), connection size based fixed monthly payments (€/month), or combination of both. The electricity tax is energy-based and electricity retailers’ tariffs are often energy-based also including a fixed part. In Finland, power network operations are a natural monopoly. DSOs’ pricing is not directly controlled, but the annual revenue of DSOs’ is regulated by Finnish Energy Authority to ensure reasonable pricing. Further, the tariff structure is not controlled, but pricing should reflect the caused costs.
Tariff structures have to be easily understandable and tariffs have to be available for all same type of customers of a DSO [4].

**Power-based tariffs**

PBTs have been proposed as a new tariff structure that considers the costs caused by an individual customers in a better manner. In power-based tariffs, part of the distribution bill is collected by charging customers for peak power. However, there have been different suggestions, regarding the methodology to bill tariffs for peak powers.

Two DSOs in Sweden have already introduced power-based tariff system [5],[6]. These companies charge a fixed monthly payment depending on the main fuse size and power-based payment, which is determined by the average of the three highest monthly customer peak loads besides 7 am and 7 pm. The price is higher in the wintertime.

**METHODOLOGY**

Different parameters on tariff structure can have significant influence on how customers use electricity. The price for the power tariff can be estimated with

\[
P_{nt} = \frac{R}{\sum_{i=1}^{n} \sum_{tp=1}^{ntp} (\hat{P}_{tp})}
\]

where \(p_{nt}\) is the power tariff price (€/kW), \(R\) is the desired revenue, \(n\) is the number of customers, \(ntp\) is the number of time periods and \(\hat{P}\) is customer's bill-defining peak load inside time period \(tp\).

**Different PBTs**

Customers’ peak loads can be taken into account with different tariff structures [7]. The considered PBT tariff structures are so called 1) power band and 2) load demand pricing model [8].

**Power band pricing**

In the power band model, a customer orders the power band in advance and then he can use electricity for same monthly payment for DSO without limits as long as demand doesn’t exceed the power limit of the chosen power band. This model would encourage customers to reduce their power peaks by reducing their power consumption or shifting the consumption to non-peak hours. From DSOs’ point of view, the power band model would lead to an easily predictable situation. Compared with the present energy-based pricing models the DSOs could dimension their grids more cost-effectively and estimate the incomes of the customers more accurately. Customers with no consumption in the considered time period will be charged for the lowest power band available. However, there are some problems with the power-band-based pricing. For instance, what is a good price for the customers who exceed their power band [9]. This kind of pricing model has been studied in literature but not taken into account [9],[10].

Fig. 2 demonstrates the principle of power band pricing with 2 kW power band steps.

**Load demand pricing**

The second considered model is so called load demand pricing where the customers are charged afterwards for exact peak hourly demand realized in the time period. This type of peak load demand pricing models are already used for bigger customers, such as industrial customers. Because the distribution fee is based on measured peak powers, the model does not charge customers, if they do not use electricity in the considered time period, which is problematic from grid cost perspective. Hence, this kind of pricing model should also include some fixed fee or predefined minimum charged power as is posed as an option in [7]. Load demand tariff is demonstrated in Fig. 3.

Fig. 2 Principle of power band pricing in annual and monthly time periods.

Fig. 3 Principle of load demand pricing in annual and monthly time periods.

**Different time periods**

PBTs can be implemented with many options for the time
period. Changing the time period has effects on customers’ annual electricity bills and can affect how customers change their consumption. If the time period is set shorter, for example as daily power tariff (DPT) or weekly power tariff (WPT), customers might not change their consumption since it does not significantly change electricity bill. On the other hand, if the time period is set to be long, such as monthly power tariff (MPT) or yearly power tariff (YPT), customers that have already had high load during that time period, might not have incentives to limit their load before the next time period. Fig. 4 shows an example of customer's peak powers for different time periods.

**Fig. 4 Customer peak loads for different time periods.**

**CASE AREA ANALYSIS**

The case study is done with the data of a Finnish DSO’s, Nivos Oy. The case area includes more than 14000 customers from both, rural and urban areas. In the case study, only small low-voltage customers are taken into account, which limits the number of customers to about 13800. Customer group includes, for example, detached houses, row houses, apartments, farms, business customers and public services. The heating type of individual customers is not accurately known, but the data includes both customers whose consumption is clearly outdoor temperature dependent and those whose consumption is not. In Finland, a local speciality is numerous electric sauna stoves, which can cause customers' demand peaks.

**Assumptions**

In the case area analysis, only customers with main fuse size 3x100A or lower are considered. This limitation was made to study household size customers’ distribution pricing in more detail. Customers with no consumption were assumed to be connected and paying for a minimum power band. Customer payments are estimated with metered consumption data, and possible future changes in consumption patterns are not modeled in the case area analysis. The price for peak power is assumed to be constant irrespective of time in tariff structure, but changing time period length affects the unit price.

**RESULTS**

The case area study shows that customers’ payment can be divided differently between customers if different power-based tariffs are used. Figure 5 shows how customers’ share of DSO revenue is divided between different customers in the case of 1 kW power band model and different time periods. In Fig. 5 – Fig. 7, time period called season divides year to two time periods, from October to March and from May to September.

**Fig. 5 Changes in customers' share of distribution revenue with different time periods in 1 kW power band model.**

It can be seen from Fig. 5 that the shorter the time period gets the greater changes in customer payment shares are. About 6000 customers pay smaller share of distribution bills in the case of DPT compared to YPT. Fig. 6 and Fig. 7 show how customer payments divide between different customers in the case of load demand tariff and in the case of 5 kW power band model and different time periods.

**Fig. 6 Changes in customers' share of distribution revenue with different time periods in the 5 kW power band model.**
It can be seen from Fig. 6 that with 5 kW power band model, there is a large group of customers who will pay higher share of DSO’s revenue if the time period is shorter. This is because their consumption is always under the lowest power band, 5 kW, and other customers can have lower power bands in shorter time periods.

In reality customers would not be able to choose always the optimal power band in advance, which would affect payments. In the power band model the customers’ peak powers have to be decided in advance, which could possibly activate customers to consider, how they consume electricity and how the power band could be reduced.

Fig. 8 shows a comparison of a shorter time period tariff MPT and longer time period tariff YPT as a function customers’ full load hours in the case of 1 kW power band model.

Fig. 8 Changes in customers’ share of distribution revenue with different time periods compared to customers' full load hours.

It can be noticed that shorter time periods lead to higher payments for customers with stable consumption patterns (high full load hours). In a way these customers use grid capacity more efficiently. For this reason longer time periods can be reasonable at least in operation environments where seasonal differences are significant and seasonal peak loads affect the grid dimensioning. In environments where peak loads in distribution grids are more dependent on time of day, shorter time periods can be more reasonable. On the other hand, if customers are given an incentive to reduce their peak loads and flatten their load curve, loads in some grid components may increase. This might happen, if the peak powers of different customers had originally time alternation, but reduced peak loads were shifted to the same time as can be seen in [11].

Fig. 9 shows a load curve of a customer that would benefit from the tariffs with shorter time periods.

Fig. 9 Example of a customer that will benefit from shorter time period.

Time period of power-based tariffs affect considerably unit price per kilowatt. In Table 1 unit prices that would have satisfied the revenue goal are estimated according to year 2014 AMR data. The unit prices are shown in relation to price of 1 kW year power band tariff.

Table 1 Peak power unit prices in different structures compared to 1 kW year power band model peak power unit price. The unit prices have been scaled to year level for comparability.

<table>
<thead>
<tr>
<th></th>
<th>1 kW power band</th>
<th>5 kW power band</th>
<th>Load demand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>100.0</td>
<td>79.1</td>
<td>106.6</td>
</tr>
<tr>
<td>Season</td>
<td>113.0</td>
<td>86.5</td>
<td>121.7</td>
</tr>
<tr>
<td>Month</td>
<td>142.2</td>
<td>101.1</td>
<td>156.8</td>
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<tr>
<td>Week</td>
<td>167.4</td>
<td>111.2</td>
<td>189.2</td>
</tr>
<tr>
<td>Day</td>
<td>231.2</td>
<td>132.6</td>
<td>275.7</td>
</tr>
</tbody>
</table>

It can be noticed that shorter time periods lead to
significantly higher unit prices. The unit prices are still highly dependent on DSO’s operating environment. In practice, customers’ consumption pattern changes should be taken into account before introducing new tariff structure.

**CONCLUSIONS**

The case study shows that different power-based pricing models with different time period options can have significant impact on how DSO’s revenue is collected from customers. The time period has also great effect on unit prices of power pricing component. Especially the customers, who would have the minimum power band, will have to pay greater share of DSO’s revenue if the time period in the tariff is short.

In practice time periods shorter than one month are complicated in power band models for customers, because choosing short time power band would require good knowledge of own electricity consumption. Short time periods do not give so significant incentives to reduce seasonal peak loads. Shorter time periods could be better in operating environments, where time of day affects more to peak powers in the distribution grid than seasonal differences.

The grid costs are highly dependent on peak powers on distribution system, so DSO pricing should be dependent on customers’ peak powers. Load demand tariffs should include a fixed payment or minimum peak power payment to cover grid costs even on periods when customer does not use electricity. In the power band model customers always pay at least for the minimum power band.

**REFERENCES**


