Power-Based Distribution Network Tariff of Small Customers in Different Operational Environments – Case Study of Two Networks

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***Abstract*—This paper discusses the aspects of the development of the pricing of electricity distribution. The operational environment of the Distribution System Operators (DSO) is changing due to various factors. The DSOs have to take actions in order to ensure that the qualifications for a stable and sustainable business are still present in the future. One way to ensure this is that the DSOs start developing their pricing practices. Especially tariffs, which include a capacity related component, are seen as a potential development direction. The paper includes a case study of power-based pricing, where data from two Finnish DSOs are applied. The results show that the customer impacts in both cases would not be massive for the majority of the small customers, which is central from the successful tariff reform viewpoint. Additionally, two Finnish DSOs have gradually started to apply a power-based distribution tariff (PBDT) to their small customers.**

***Index Terms*—Power-based distribution tariff, pricing of electricity distribution, small customer tariffs, tariff development, tariff reform**

I. INTRODUCTION

In the electricity sector, discussion regarding the present state and the development needs of distribution tariffs of small customers has been globally active in the recent years [1]-[6]. The present pricing schemes of Distribution System Operators (DSO) are still widely energy-dependent and the changing operational environment challenges the present pricing practices of the DSOs. In the future power system, the roles of different electricity market actors have to be clear and, from this viewpoint, the key mission of the DSO is to provide a neutral platform, which enables the operation of various electricity market actors. The tariffs of the DSO cannot set unfounded limits to the operation of other market actors.

This paper is a continuation of an ongoing research work presented in e.g. [7]-[12]. The work aims to investigate the potential distribution tariff reform in Finland and especially the application and impacts of power-based distribution tariffs (PBDT) of small customers. The focus in the paper is on the Finnish electricity market but the results of the paper can be utilized globally. Regarding the tariff reform, two Finnish DSOs have already started to gradually apply a tariff which includes a power charge (€/kW) to their small customers [13] [14]. The tariff structure in these cases is similar to what has been applied for a long time to larger customers. Although the implementation of novel distribution tariffs has not yet been seen on a larger scale in Finland, a growing interest towards alternative pricing schemes of the small customers can clearly be perceived.

In the paper, we aim to answer the following four key research questions:

1. What kind of a distribution tariff structure would serve the various electricity market participants the best in a deregulated electricity market?
2. Would the prices of the PBDT differ substantially between two studied networks having various operational environments?
3. What are there major differences in the customer impacts, when a selected PBDT is applied to small customers in the two case studies?
4. How could the transition towards the PBDT from present distribution tariffs take place?

The first research question is answered in the second and third sections, where the needs for distribution tariff reform are explained and various PBDT structures are reviewed. The second research question is discussed through a study, where data from two DSOs is applied. The studied networks are located in different areas and the results show whether the studied PBDT structure would substantially alter from each other. The results, as such, do not state what the actual pricing of the DSO should be in a real implementation. The data covers only a fraction of the whole networks of the DSOs and there are various other factors affecting the pricing, which cannot fully be taken into account in the study. The third question is also answered by the study, which investigates the impacts of the selected PBDT structure on the distribution fees of the customers and on the revenue of the DSOs. The last question is addressed by discussing how the selected PBDT could be implemented in practice.

The paper is structured as follows. In the second section, information about the distribution tariffs applied in Finland and a compact view about the reform needs regarding the tariffs of small customers are provided. The third section includes a description of recently studied novel distribution tariffs in Finland. In the fourth section, a case study is provided where data of two Finnish DSOs is applied. The fifth section includes the results of the study. The last two sections provide the discussion and conclusion to the paper.

II. NEED FOR DISTRIBUTION TARIFF REFORM

The interest towards alternatives in pricing of electricity distribution has been on the rise in the recent years. Various upcoming changes in the operational environment challenge especially the present distribution tariffs of small customers. In this section, we present a brief overview of the present state of the distribution tariffs of small customers and a description of some of the central future challenges. Additionally, we provide insight regarding the potential tariff development directions of the DSOs.

A. Present distribution tariffs of small customers in Finland

The present widely applied tariffs of small customers consist mainly of two tariff components: a monthly base charge (€/month) and a volumetric consumption charge (c/kWh). At present in Finland, the emphasis of the consumption charge is still quite significant, although the trend has been such that the DSOs have been slowly shifting the emphasis to the base charges for the past fifteen years.

For larger customers there are additional components for active (€/kW) and reactive power (€/kvar) in the tariffs. Due to the lack of sophisticated metering systems (i.e. smart meters) it has not been in practice possible to apply a more flexible tariffs for small customers. Today, the situation is different since the smart meter rollout has been implemented in Finland. The energy consumption of practically every customer is measured hourly by the smart meters and the data is remotely collected from the meters by the DSOs.

B. Change drivers

The development needs regarding the distribution tariffs arise from the central challenges of the future. For example, the present tariffs enable cross-subsidies between customers of different consumption behavior. This viewpoint is relevant especially when customers acquire more microgeneration (e.g. photovoltaic systems) for being prosumers. The decreasing amount of electricity transferred through the grid pressures the DSO to compensate the decreased revenue by raising the price level of the tariffs. This makes the customers, who only consume electricity, pay even more although the prosumers still, as well, cause costs for the DSO. From a more general viewpoint, the central mission of the DSO tariffs is not to subsidy the prosumers with the cost of others. The DSO should primarily provide a neutral platform for various actors of the electricity market to operate in. The boosting of microgeneration could be done alternatively e.g. though taxation or through some other instrument.

In addition to the viewpoint regarding the cross-subsidies, the present tariff structure does not reflect well the cost structure of the DSO. A significant part of the costs of the DSO derives from the network capacity (i.e. power) rather than from the amount of energy delivered to the customers. [1] [2] Volumetric consumption charges encourage the customers towards traditional energy efficient consumption, but the signal, from the DSO viewpoint, is not linked to the actual cost driver (i.e. network capacity, power). By sending a proper signal to encourage the customers to consume electricity in an efficient way, from the network perspective, it could lead to a higher utilization rate of the network. When the DSO is able to serve more customers while avoiding possible network reinforcement costs, both the DSO and its customers can face long-term benefits. For example, the costs of the DSO can reduce which eventually leads to a lower price level of the tariffs.

Through the pricing, it is also possible to enable the business development of other electricity market actors. The development towards a more efficient and smarter energy system is also a significant goal from the societal viewpoint.

C. Potential development directions

The DSOs have various options to respond to the challenges of the future. For example, the way can be one of the following options. [10]

1. Raise the emphasis of the base charges (€/month).
2. Raise the price level of the volumetric consumption charges (c/kWh) when total revenue starts to decrease.
3. Develop the pricing through novel tariff solutions.

From the listed options, the third would present itself as a more long-term solution whereas the first and the second options appear as more of a temporary solutions aiming to delay the inevitable need for change. Regarding the development direction of distribution tariffs, the PBDTs have been discussed very actively in Finland, and globally [1] [2] [15]. The power-based pricing has been seen as a promising alternative for present tariffs, and thus, our focus in the paper is mainly on various PBDT structures.

III. POWER-BASED DISTRIBUTION TARIFFS

On a more general level, the PBDT means a tariff, where the power demand of the customer is taken into account in more detail than how it is applied in the present tariffs. There are various ways to include power (kW) in the distribution tariff. For example, power can be taken into account e.g. by

1. Linking the power to the magnitude of the fixed part of the tariff (€/month or year).
2. Linking the power to the magnitude of the volumetric consumption charge (c/kWh)
3. Using a separate charge for power (€/kW).

The listed options become relevant when the tariff structure is under discussion. For example, to some degree, the first of the listed options is applied today in Finland by many DSOs, which offer a tariff where the magnitude of the base charge depends on the fuse size of the customer (i.e. larger capacity carries a higher base charge).

In this paper, our timeframe for the term power is one hour, which is the present market unit used in the Finnish day-ahead electricity market and for the balance settlement. Therefore, when the term power is used, we mean the hourly average power (i.e. the measured hourly energy). However, this does not mean that the power could not be calculated from a shorter period in the future.

A. Alternative power-based pricing schemes

There are many alternative tariff structures for the DSOs to be considered. In Finland, various PBDT structures have been recently studied and their properties have been reviewed from the viewpoints of various electricity market actors. Four tariff options have been studied more thoroughly: the power limit tariff, the step tariff, the power tariff with a threshold power and the power tariff. [11] [15]

The power limit tariff consists only of a power charge (€/kW) determined by the capacity need of the customer. In the price list of the DSO, there would exist a predefined selection of power limits such as 5 kW, 10 kW etc. and the customers are placed under the limit closest to their peak hourly demands (e.g. of the previous year(s)). The customer in this tariff would pay a flat monthly charge determined by the power limit. If the customer exceeds the set limit, it would carry a sanction e.g. the customer is placed to the next power limit to face a higher distribution fee for the next 12 months.

The step tariff consists of two tariff components: a monthly base charge (€/month) and a volumetric consumption charge (c/kWh). In this tariff, the magnitude of the consumption charge depends on the hourly consumption. For example, if the hourly consumption of the customer exceeds 5 kW, the unit price of the charge is higher for the whole hour than what it would be under the limit.

The power tariff with a threshold power consists of three tariff components: a fixed monthly base charge (€/month), a volumetric consumption charge (c/kWh) and a power charge (€/kW). In this tariff, the power charge is in effect when the monthly peak consumption of the customer exceeds a certain limit e.g. 5 kW. With lower peak consumption, the customer faces a similar tariff structure as they do today.

The power tariff is similar to the previous tariff. The only difference is that this tariff has no threshold in the power charge. This means that the power charge is applied for all customers regardless of their consumption level and the tariff consists of a monthly base charge (€/month), a power charge (€/kW) and of a volumetric consumption charge (c/kWh).

B. Implementation viewpoints and selected PBDT structure

For the tariff to be successful, it is important that the tariff is also relatively easy to implement and the basic mechanisms of the tariff have to be simple enough for the average customer, who are not typically experts in the field of tariffs, to understand. It has to be emphasized that the understandability of the tariff does not in itself mean the number of the components in the tariff and the tariff consisting of least components is not necessarily the simplest option to implement in practice.

A comprehensive analysis has been conducted regarding each of the discussed tariff options from various perspectives to determine which of the PBDT structures could be the most suitable candidate for the future tariff structure for small customers in Finland. Based on the results presented e.g. in [11] and [15], we have selected the PBDT structure used in the case study to be the power tariff, which has been seen as a stronger candidate compared to the other discussed options.

IV. CASE STUDY

In the study, we investigate a selected PBDT structure by applying data of two different DSOs. The studied networks are located in different areas and the results show whether the PBDT would differ substantially in these networks. The PBDTs used in the study have been formed based on cost-causation meaning that the rates are designed to reflect the cost structures of the networks.

The main difference between the two DSOs regarding the pricing is that, in the first network, there is only one base charge (€/month) inside the same tariff and the base charge is the same for all customers of the tariffs (i.e. there are more than one tariff for the customer to choose from). In the second network, the magnitude of the base charge depends on the connection size of the customer (i.e. larger fuse capacity results in higher base charge). In this area, there are also multiple tariffs each with their own base charges.

A. Assumptions and calculation principles

In the study, the power tariff is formed based on the costs of the studied networks. To compare the impacts of the PBDT, present tariff structures were also formed. The PBDT in both networks is the power tariff consisting of the following tariff components.

1. Monthly base charge (€/month).
2. Volumetric consumption charge (c/kWh).
3. Power charge (€/kW).

The basis of the monthly power charge is the average of five highest hourly powers of each month. This selection is based on an earlier research work presented in [9], where this option resulted to a revenue closest to the target revenue. There are many other possible options for the power charge basis and the aforementioned option is selected for this study.

In the calculation, we apply the hourly consumption data (i.e. hourly energy measurements) from years 2013 and 2014. The data from the former year is used to determine the tariffs for the next year and the data from the latter year is used as the realized consumption. The costs of the network areas are allocated to the customers according to their assumed use of electricity. This means that the effects of the PBDT on the consumption behavior are not considered through e.g. load optimization on the customer level. The main focus of the study is on the tariffs of small customers. In the calculations, the effects of the larger customers are taken into account, but they are not in the scope of this paper.

It has to be emphasized that the networks of this study do not represent the whole distribution system of the DSOs since they cover only a fraction of their customer bases. Consequently, the results do not imply what the pricing should be in a real implementation as the tariffs produced for the study reflect only the limited areas in question, not the complete operational areas of the DSOs.

B. Network I – City area

The network I is located in a city area. The number of customers in the area in question is ca. 32 000, majority of them being small customers (over 98 %). In the city network, the average length of conductors (i.e. cables and overhead lines) per customer is relatively small, roughly 9 meters per customer on the low voltage level and around 3 meters per customer on the medium voltage level.

According to the cost analysis performed for the network, the total revenue requirement for the network is roughly 6.9 M€ from which 4.4 M€ is to be collected from the small customers based on the cost allocation calculation (i.e. the target revenue).

C. Network II – Mixed urban and rural area

The network II is located in a mixed urban and rural area. The total number of customers in the area in question is nearly 8 100, all of which are connected to the low voltage network. The majority of the customers in the network are also small customers as in network I but in this network, the average length of conductors per customer is considerably higher, roughly 111 meters per customer on the low voltage level and around 59 meters per customer on the medium voltage level.

According to the cost analysis performed for the network, the total revenue requirement for the network is roughly 3.0 M€ from which 2.7 M€ is to be collected from the small customers based on the cost allocation calculation.

D. Distribution tariff parameters

Based on the cost and consumption data, presently used distribution tariff structures were formed based on the cost-causation principle in a similar manner as presented in [7] and [9]. In addition to the present tariff structures, the selected PBDTs were also formed based on the cost structure of the two networks. The formed PBDTs are presented in Table I.

TABLE I. CALCULATED TARIFF PARAMETERS OF THE POWER-BASED DISTRIBUTION TARIFFS FOR THE STUDIED NETWORKS

Tariff component	**Network I**	**Network II**
Base charge (€/month)	4.03	3.82
Power charge (€/kW, month)	3.46	6.60
Volumetric consumption charge (c/kWh)	0.53	0.58

The main difference in the PBDTs is the magnitude of the power charges. The difference derives partly from the fact that the average length of conductors per customer is much higher in network II (59 and 111 meters per customer) than in network I (3 and 9 meters per customer) and partly from the consumption behavior of the customers (i.e. urban area versus rural area). Additionally, even the structure of the network and its planning principles affect the tariffs. A significant portion of the costs is allocated to the power charges of the PBDTs according to the consumption, which makes it quite challenging to isolate the exact factors, which create the difference in the magnitudes of the charges.

V. RESULTS

The customer impacts of the PBDTs presented in the previous section are shown in Fig. 1. From the results it can be seen that there are many customers in network II, who would have experienced a smaller annual distribution fee (i.e. the annual change of roughly -200 €). There are customers in this group whose energy consumption is quite low. With the formed PBDT, it is logical that these customers would face lower distribution fees mainly because the monthly base charge is lower in the PBDT than in the formed present tariff structures. In network I, the distribution of the changes is much more even than in network II. This results partly from the present tariff structures, where there are no steps between the fuse sizes inside the same product as there are in network II. Additionally, the consumption behavior in the city is more homogeneous since most of the customers are living in apartment buildings.

From the DSO perspective, the tariffs can also affect the revenue collected from the small customers. The target revenues and the "realized" revenues of present tariffs and the PBDTs are presented in Tables II and III. Based on the results presented in the tables, the PBDTs would not have caused massive changes in the revenue, which is a very positive factor. In both networks, the PBDT would have produced a revenue, which is closer to what was achieved with the formed presently used tariff structures.

Regarding the results, it has to be emphasized that in the calculation we have not assumed the customers to react to the price signals of the tariffs (i.e. the power charge). Without the use of additional load controlling devices, the customers would not necessarily make major changes to their consumption behavior.

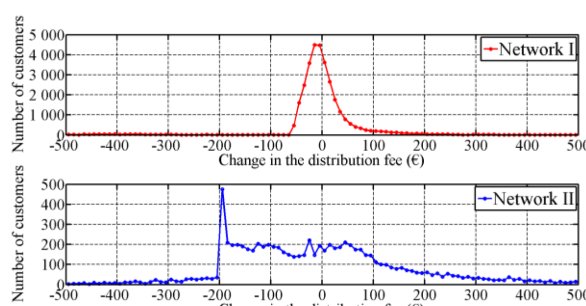

Figure 1. Changes in the annual distribution fees of customers in the studied networks with the PBDT compared to calculated present tariff structures. The range covers at least 96 % of the small customers in both cases.

TABLE II. THE TARGET AND REALIZED REVENUES GATHERED WITH THE PRESENT DISTRIBUTION TARIFF STRUCTURES OF SMALL CUSTOMERS

	Target revenue (€)	**Present tariff structures, realized revenue (€)**	**Difference to the target revenue (€)**	**Difference to the target revenue (%)**
Network I	4 471 347	4 457 996	-13 351	-0.30
Network II	2 728 810	2 748 635	19 825	0.73

TABLE III. THE TARGET AND REALIZED REVENUES GATHERED WITH THE POWER-BASED TARIFF STRUCTURES OF SMALL CUSTOMERS

	Target revenue (€)	**PBDT, realized revenue (€)**	**Difference to the target revenue (€)**	**Difference to the target revenue (%)**
Network I	4 471 347	4 473 920	2 573	0.06
Network II	2 728 810	2 728 818	8	0.00

VI. DISCUSSION

The results show that the selected PBDT differs between the two studied networks in terms of the power charge. However, it is more important that the customer impacts of the PBDT would not alter substantially between different kinds of networks if the PBDT would be implemented widely at the same time. In the studied networks, the impacts would not be too unreasonably different from each other (i.e. in both cases, the majority of annual changes fall between ± 200 €), which is a clearly positive factor from the tariff reform point of view.

The practical implementation of the PBDT can be done either overnight or gradually. However, in the former solution, the customer impacts would be higher for some of the customers as shown in Fig. 1., or rather outside the scope of the range of the figure. If the DSOs were to implement a PBDT for small customers, the transition would have to be made in smaller steps and the whole transition period would take a longer time (e.g. five or more years). In the first step of the transition, assuming that the target PBDT would be the one proposed in the paper, the magnitude of the power charge would have to be relatively low so that the DSOs and the customers would have enough time to adapt to the changes. The values presented in Table I represent more of the extremes, where the power charges are set to their maximum theoretical levels (i.e. a significant portion of the costs were allocated to the power charges) in the case of the proposed PBDT structure.

The proposed PBDT structure can also be implemented even when there are parallel tariffs for different customer types by shifting the pressure gradually from other tariff components to the power charges. Alternatively, there can also exist parallel tariffs with the same basic structure, but each tariff has its own features (e.g. Time-of-Use feature).

VII. CONCLUSION

This paper discussed the aspects of developing the pricing of electricity distribution for small customers. Various PBDTs have recently been studied in Finland and a tariff consisting of three component (€/month, €/kW and c/kWh) is seen as a very strong candidate for the future distribution tariff structure of small customers. The selected PBDT was formed for two different network areas based on the costs to investigate whether its customer impacts would alter substantially. The results show that the PBDT would, at its maximum theoretical implementation level, lead to a bit different results in the studied networks. However, in a practical implementation, the DSOs would change the tariffs gradually in order to mitigate the customer impacts. Major changes regarding the pricing practices have to be planned carefully in order for the transition to be successful. It has to be emphasized that the results presented in this paper do not propose what the structure of the tariffs or their price level should be in real implementation. There are various factors, which affect the pricing and there is no universal one-size-fits-all solution for the pricing of electricity distribution.

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