Cost-causation based approach in forming power-based distribution network tariff for small customers

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***Abstract*—This paper discusses the development of electricity distribution network tariffs. In the paper, the present state of distribution network tariffs of small customers is discussed together with key future challenges of the distribution network business. As a potential solution to these challenges, power-based tariffs of the small customers are discussed and preliminary results of a case study are presented where tariffs are formed by applying data of one Finnish Distribution System Operator (DSO).**

***Index Terms*— Electricity distribution business, electricity distribution network tariff, power-based distribution tariff**

I. INTRODUCTION

In countries where the electricity market is unbundled, DSOs and energy retailers operate separately. DSOs gather their revenues by distribution network tariffs. The electricity distribution network business is operated by the DSOs who have local monopoly positions due to the fact that it is economically ineffective to build multiple electricity distribution networks inside the same area. The monopoly position has not encouraged the DSOs to considerably develop their pricing practices. In the future this is expected to change. The electricity distribution network business will face challenges in the future and actions have to be taken to make sure that the business will remain on a sustainable and profitable level.

The purpose of this paper is to discuss of the possibilities and aspects of forming a power-based distribution network tariff for small customers. By a power-based distribution network tariff we mean a tariff structure, which has some kind of a demand pricing component based on measured power. This paper discusses the aspects concerning the benefits that could be brought also to the smaller customers by implementing a power-based distribution network tariff. In the paper, the power-based distribution network tariff of smaller customers is formed based on the assumed cost structure of the DSO which is formed based on the value of the network assets. This approach differs from e.g. the approach where present tariffs of the DSO are applied to customers and the alternative distribution network tariff structure is formed to be revenue neutral with the present tariffs. For the consumption analysis we used the hourly load data of two consecutive years in the calculation process.

In the past, the implementation of power-based tariffs for smaller customers was not practically possible since the traditional metering infrastructure did not have the needed characteristics to support this kind of a tariff structure based on measured powers. The situation today is quite different and many opportunities arise from modern technology such as the smart meters.

Various distribution network tariff structures and pricing development options have been previously discussed in [1]-[5]. From different development options, tariffs which have some kind of a demand component have been considered as potential options due to their effects such as improved cost-reflectivity of the tariffs (i.e. the tariff structure itself reflects the cost structure of the DSO in a better way) and giving the customers better control over their electricity bills. The aspects concerning power-based distribution network tariffs are discussed in the following sections more thoroughly.

This paper is structured as follows. First, in section two, the present state of electricity distribution network tariffs is discussed. In section three, some upcoming central challenges are listed and explained. The fourth section discusses the motivational keys for developing distribution network tariffs. The fifth section presents the preliminary results of a short case study where a power-based distribution network tariff is formed for small customers based on real DSO data.

II. ELECTRICITY DISTRIBUTION NETWORK TARIFFS

There is a selection of distribution network tariffs for different kinds of customers. In the following, the general structures of distribution network tariffs in the case of smaller and larger customers are discussed.

A. Typical structure of distribution network tariffs

The typical composition of distribution network tariffs offered to small customers consists of a fixed charge (i.e. €/day, month or year) and a charge depending on the amount of electricity distributed (i.e. cent/kWh). For example in Finland in rural areas, the fixed charge depends on the size of the connection of the customer (i.e. the number of phases and the main fuse size). In some countries, the energy charge can have different price levels for different types of hours such as night time and daytime (i.e. Time-of-Use tariff (TOU)). Also in some European countries, small customer tariffs include a capacity charge component, usually based on contracted power (€/kW) which forms the "fixed charge" of the tariff. The power is usually not the measured power, but based on a predefined limit. [1]

Where the tariffs for small customers are structurally quite inflexible, the tariffs offered to larger customers, such as industrial or large commercial customers, are more flexible. These tariffs also include separate charges for active power demand (i.e. €/kW) and reactive power (i.e. €/kvar). This enables the customer to actively affect the amount on their electricity bill by planning their consumption more carefully e.g. by minimizing simultaneous power demand caused by the use of several appliances.

B. General notions about tariffs of small customers

The distribution network tariffs of small customers have been more dependent on the variable part of the tariff (i.e. the energy charge) than on the fixed part (i.e. the fixed charge). However e.g. in Finland, the portion of the fixed charge has been on a slow raise during the past years but still the ratio between the fixed and variable part does not fully reflect the cost structure of the DSO. The direction of change is correct but the cost reflectivity of the tariffs (i.e. in the case where the structure of the distribution tariff would reflect the cost structure of the DSO) is still not as strong as it could be. A large portion of the costs of the DSO is dependent on power capacity rather than on energy [2].

The structure of the tariffs of small customers is typically so that the fixed part of the tariff is the same for all customers of the same tariff group regardless of their actual consumption. This could, in some cases, mean that the smaller customers subsidize the larger customers inside the same tariff group or vice versa.

III. Main upcoming challenges

If the distribution tariffs are to remain unchanged, the future development of the energy sector may create pressure for the business of the DSOs. This encourages the DSOs to make an effort to review their pricing practices. In the scope of this paper, four relevant key factors which might have a meaningful effect on the business of the DSO are described and discussed.

A. Distribution grid capacity

The present distribution grid on the European level is quite old and thus the rebuilding of the aging grid has become timely. Traditionally the grid is planned to withstand the highest estimated simultaneous load. For example in Finland, the electricity distribution grids are quite strong due to e.g. electric space heating, water boilers, sauna and electric ovens which means that also in low voltage networks a three phase system is used. Distribution grids are able to withstand the high load peaks which occur during winter when the heating demand is high. On the contrary, during summer when the power need for heating and lighting are minor there is excess capacity in the distribution grids.

B. Growing amount of small-scale disributed generation

Another key change factor is the increasing amount of small-scale energy production at the customer premises (i.e. photovoltaic production units). This has an effect on the amount of electricity distributed to the customers. This combined with the present structure of distribution network tariffs can turn out problematic for the revenues of the DSOs. The amount of electricity delivered decreases due to the raising amount of distributed energy generation and thus the revenues of the DSOs also decrease. This development does not remove the responsibility of the DSOs of maintaining and developing the distribution networks to serve all the customer loads and productions. The costs of the network assets and operation may increase when responding to the changes in the operating environment.

C. Changes in the consumption

From the consumption point of view, the changes in the customer behavior have to be noted when the DSOs re-evaluate their distribution network tariffs. Different large individual electrical appliances such as heat pumps and electric vehicles can challenge the electricity network in terms of power since they are probable to grow the consumption peaks. The simultaneous switching of the loads can cause quite a high demand which the network has to sustain. This becomes highly relevant in cases where the customers have more and more energy supplier tariff, where the price of the energy is linked e.g. to the day-ahead market price of wholesale electricity market. If the energy price varies a lot from hour to hour, the customer would have the incentive to consume more electricity during cheap energy hours as one optional demand response (DR) functionality. This would result in high simultaneous power demand that could be substantially higher than today. This challenges the tariff structure of the DSOs since the simultaneous demand is a central cost driver for the DSO.

D. Legislative point of view

One additional key challenge comes from the legislative point of view. In Finland, the legislation emphasizes the role of reliability of supply. The DSOs are pressured to make their networks more immune to weather and this typically means underground cabling. The costs of these legislative issues have caused pressure to the DSOs to raise the price levels of their tariffs to gather enough revenue in order to fund these improvement investments made into the network. The rising prices have evoked some discussion amongst the customers and it has been noted also by the media.

IV. ALTERNATIVE DISTRIBUTION NETWORK TARIFFS

The aforementioned challenges motivate the DSOs to develop their pricing practices. If the tariffs are not reviewed and new pricing schemes developed, the DSOs would raise the price levels of their present distribution network tariffs. DSOs will have to ensure an adequate level of revenue to be able to continuously maintain and develop the distribution network.

A. Alternative tariff structures for small customers

In the literature, many different options have been studied when alternative distribution tariffs are considered for small customers. For example Critical Peak Pricing (CPP) has been discussed in [3]. This tariff structure is relatively similar to the TOU tariff. There are different price levels for the energy charge (i.e. c/kWh). For some hours of the year, the DSO sets the price of the energy charge to be considerably higher compared to other hours of the year. The purpose of higher price is to encourage the customers to shift demand to cheaper hours when there is more available capacity in the network.

B. Power-based distribution network tariff for small customers

In response to the aforementioned challenges the DSO could develop new distribution network tariff pricing for small customers. Different power-based distribution network tariff structures could prove to be viable solutions to the changing business environment. For example, the power-based distribution network tariff would reflect the cost structure of the DSO better because the costs of the DSO result from the capacity related costs. Power-based distribution network tariffs would send the right signals to the customer when power demand related components are used in the pricing. In terms of cost-causation, power-based distribution network tariffs would be a better solution than present tariff structures. Cost-causation in this paper means that the customers who inflict the costs should pay for them. The power demand component in the distribution network tariff could realize the cost-causation in a better way than what e.g. the present fixed charges of the tariffs do.

There are optional ways to implement a demand component in the distribution network tariff, but in this paper the structure of a power-based distribution tariff is considered to consist of three components: fixed monthly charge, charge related to energy consumption and monthly demand charge based on the selected peak power of the month. The demand charge is therefore based on the measured power, not on the contracted power. Linking the demand charge to the measured power would give the customer an incentive to actively change the consumption behavior of the customer in a way that the distribution fee would be as low as possible.

V. CASE STUDY

The short case study presented in this paper demonstrates what the power-based distribution tariff could look like when it is formed using real customer and network data combined with real consumption data and an assumed cost structure.

A. Data used in the case study

The customer data used in the case study is based on a real customer, network and consumption data from a Finnish DSO. The part of a network in the study does not represent the whole network of the DSO in question and it should be emphasized that the results of this case study, as such, do not propose final distribution tariffs which we would recommend to be implemented for the customers of the DSO. The results presented here are not final and many other principles and practical aspects have to be noted so that the tariffs would fulfill the demands set to them.

The calculations here were made by applying data from the years 2013 and 2014. The data used in the calculation was received from the DSO in the autumn of 2015 and since the calculation of distribution network tariffs in this case demands information from two full consecutive years, we used the information from 2013 and 2014. The load forecasts used in the tariff calculation were made based on the information from 2013. The forecasts for the year 2014 were created so that for tariff groups statistical load models were used. For individual customers, the consumption measurements from the previous year were used in deducing the hourly power demands of the customers in more detail. The modelled part of the distribution network in question consists of two primary substations where there are altogether three primary transformers. The medium voltage network consists of 30 medium voltage feeders supplying a total of 103 secondary substations.

The total number of customers in the data set is over 32 000, most of them being small customers living in apartment buildings. The network in question is located in an urban area. There are also some larger customers in the network, but the key focus of this case study is on the smaller customers.

The revenue requirement used in the study is based on the reacquisition value of the network in question and on publically available financial reports of the company. From these, a cost structure was made for the network. The total revenue requirement in the case study is assumed to be around 6.9 million euro which has to be collected from all customers in the form of distribution network tariffs. It should be noted that the tariffs formed in this section are not the actual tariffs used by the DSO. The tariffs are calculated by combining the cost structure with consumption data.

B. Tariff calculation principles

The distribution tariffs are formed by using similar methods as described in [4]. In the case study, the distribution network is considered to be a so called “power delivery channel” where the costs related to power demand are allocated to different customer groups in relation to their participation to the voltage level coincident peak demands (i.e. in this case low and medium voltage levels). The costs are allocated to different tariffs in the following manner:

- Depreciations and portion of the operational costs are allocated to power or fixed charges.
- Costs of losses and transmission use-of-system charges are allocated to energy charges.

- Costs relating to e.g. metering and customer service are allocated to fixed charges.

The approach used here in practice means that when tariffs are formed, around 80 % of the assumed total costs were allocated to power or fixed charges of the tariffs. When a power-based distribution network tariff is formed for small customers, around 60 % of the assumed total costs are allocated to the power-related charges.

C. *Results*

The results of the calculation are presented in Tables I and II. In Table I, the price list consisting of present tariff structures used by the DSO is presented. There are four different tariff groups for different kinds of small customers. The new tariffs were formed so that they would be structurally the same as the present tariffs of the DSO but the unit prices are based on a theoretical approach. It should be again emphasized that these results do not propose what the price list should be in a real implementation.

In Table II, the power-based distribution network tariff structure (excluding taxes) for small customers is presented. The power charge of the tariff is formed so that the power used for the billing period (i.e. month) is defined by the highest monthly forecasted or measured load of the customer during hours between 7 a.m. and 22 p.m. To clarify this choice it should be stated that the choice is arbitrary and it is based on the present practice of the DSO for its larger customers. In this study, the energy charge was formed so that it has only one price for all hours of the year.

TABLE I. DISTRIBUTION NETWORK TARIFFS OF SMALL CUSTOMERS WITH PRESENT TARIFF STRUCTURES

			Energy charge (c/kWh)	
Tariff	**Fixed charge (€/month)**	**Contract power charge (€/kW, year)**	**Other time**	**Night-time**
Tariff 1	8.90		0.53	
Tariff 2	51.73		0.67	0.46
Tariff 3	4.03	11.63	1.07	0.41
Tariff 4	11.56		0.53	

TABLE II. POWER-BASED DISTRIBUTION NETWORK TARIFF OF SMALL CUSTOMERS

Tariff	**Fixed charge (€/month)**	**Power charge (€/kW, month)**	**Energy charge (c/kWh)**
Power-based distribution tariff	4.03	3.03	0.53

In Table III, the revenues gathered from small customers are presented. The first row of the table presents the situation where the customers would have been assigned to the tariff groups listed in Table I. The second row of Table III depicts the situation where all small customers would have selected the power-based distribution network tariff.

TABLE III. REVENUES OF SMALL CUSTOMER TARIFFS IN THE CASE OF PRESENT TARIFF STRUCTURES AND POWER-BASED DISTRIBUTION TARIFF

Case	**Target revenue (€)**	**Realized revenue (€)**	**Difference to target revenue (€)**	**Difference to target revenue (%)**
Present tariff structures	4 507 767	4 505 339	-2 427	-0.05 %
Power-based distribution tariff	4 507 767	4 543 697	35 930	0.80 %

The customer specific changes in the distribution fee of the calculation period (i.e. the year 2014) are presented in Fig. 1. The figure depicts the distribution of changes which would have happened if the tariff presented in Table II would have been implemented instead of tariffs presented in table I (i.e. the difference in the distribution fee which occurs from selecting the power-based distribution network tariff without taking changes in the consumption into account). Customers who experience massive changes (i.e. changes over 1 000 € which occur with less than 20 customers) in their yearly distribution fees, are excluded from the set as outliers which most likely results from classification errors in the customer data. The customers in question may have originally been assigned to a non-suitable tariff group without any later update. It can be seen that there are losers and winners when the tariff structure is changed. The absolute and relative average changes in the customer specific annual distribution fees for the year 2014 would have been 0.27 € and 1.38 % respectively. From Fig. 1 it can be seen that the majority of the customers would have experienced a change smaller than 500 € in their annual distribution fee.

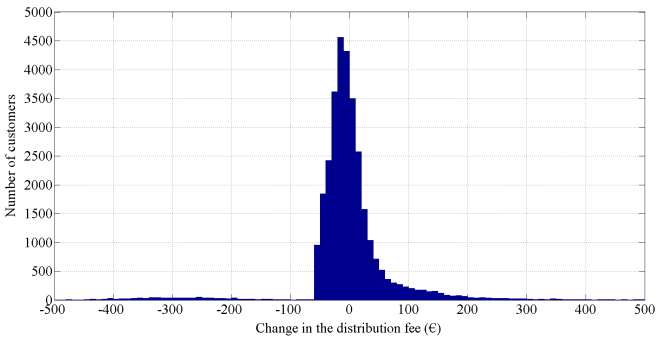

Figure 1. Changes in the distribution fees of small customers when the power-based distribution tariff from Table II would have been used instead of the tariffs from Table I

D. *Analysis of results*

The results show that the power-based tariff would affect the distribution fees. In this study, no changes in the consumption behavior of the customers were assumed. It was also assumed that all small customers would choose the power-based distribution tariffs.

The revenue collected from the small customers with the power-based distribution tariff is 4 543 697 €. The target

revenue is 4 507 767 € to cover the cost components (e.g. depreciations of network investments, losses, other operational costs and costs of metering and customers service). The difference between the realized and target revenue is thus 35 930 € meaning only slightly higher revenue (0.8 %) than what was targeted. The difference between these amounts is relatively small and it could be considered to be on an appropriate level. From the DSO point of view the change of small customer tariff structure would not cause massive change to the revenue when changes in the consumption behavior are not taken into account.

It is natural that there will be winners and losers when the bases of the tariffs are changed. However it should also be noted that the customers who have a peakier consumption behavior have been subsidized in the past by the customers having flatter consumption profiles because they have paid the same fixed charges. When the DSO starts to change the tariff structure or the price levels, it should be confirmed that the average changes would not be too high for the customers. In addition, in the case of individual customers the change in distribution fees should not be exceedingly high. This kind of a case could bring negative publicity to the DSO.

VI. Discussion

The change of a distribution network tariff structure is a delicate process. The change from present tariffs towards different alternative tariff structures would not happen overnight, as presented in this paper, but in small steps over the years in order for the customers to be able to adapt to the changes. Before possible implementation of alternative tariffs, further in-depth analysis of customer impacts is needed.

The changes in the consumption patterns caused by tariffs of the energy retailer and the DSO are beyond the scope of this paper. These changes are however highly relevant and in need of thorough research in the future. Also the actual implementation of the power-based distribution network tariff would require some kind of a display or automatic load control device for the customer to actually see the real time hourly power demand and to make sure that the hourly power or combination of some powers, which define the power part of the distribution fee of the customer, would be on a suitable level. The power-based distribution network tariff structure proposed in this paper is not the only possibility. There are many other possible power-based distribution network tariff structures. Different variations of the tariff structure and their effects to various customer types (e.g. customers of different size, customer groups and consumption behavior) are subjects for further research work.

There are also several technical factors affecting the results such as the accuracy of the forecasted monthly peak hourly powers on the customer level. The forecasts, for the majority of the customers, were done based on measurements from the previous year. Some errors occur in the data e.g. sudden peaks which are clearly errors. The measurement data was corrected manually in order to rectify the largest and most obvious errors. However, it is possible that some errors still remain in the data since it is difficult to distinguish smaller errors in the data from consumption that actually happened.

Although there are many assumptions made in the calculations it can be said that the results provide input to the discussion regarding the development of distribution network tariffs. One common counter argument against power-based distribution network tariffs has been the overly complex tariff structure which could confuse the customer. As it can be seen in Table II, the tariff structure is relatively easy to understand. Instead of several different options for the customer to choose from there is only one option. This option includes possibilities for the customer to actively affect the level of the distribution fee.

VII. Conclusion

This paper discussed the topic of electricity distribution network tariffs and the forming of power-based distribution network tariff for small customers. Some of the key future challenges are presented in this paper. Preliminary results of a case study were presented, where a power-based distribution network tariff is formed for small customers by using real DSO data. The case study shows that the structure of the power-based distribution tariff is not too complex and it gives the customers possibilities to affect the magnitude of the distribution fee. Power-based distribution tariffs can make the pricing of the DSO more transparent. From the cost-causation point of view, the power-based distribution tariff reflects the cost structure of the DSO in a better way compared to present tariff structures.

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References

[1] European commission, “Study on tariff design for distribution systems,” Report, January 2015.

[2] Eurelectric, ”Network tariff structure for a smart energy system,” A Eurelectric paper, Eurelectric, May 2013.

[3] L., Similä, G., Koreneff, and V. Kekkonen,”Network tariff structures in Smart Grid environment,” VTT, Espoo, Tech. Rep. VTT-R03173-11, May 2011.

[4] K. Lummi, A. Mäkinen, A. Mutanen and P. Järventausta. ”Electricity Distribution Pricing in Finnish Regulatory Framework – A Case Study of Matching Principle” in *2014 Proceeding of 11th Nordic Electricity Distribution and Management conf.*

[5] P. Simshauser, “Network tariffs: resolving rate instability and hidden subsidies,” Working paper 45, AGL Applied Economic and Policy Research, Oct. 2014.