Alternative Power-Based Pricing Schemes for Distribution Network Tariff of Small Customers

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***Abstract*—The development of electricity distribution pricing is becoming an increasingly relevant topic due to various factors. The Distribution System Operators (DSO) face challenges regarding their tariffs of small customers when the customers invest in energy efficiency and small-scale energy production. Thus, the DSOs must evaluate their pricing practices to maintain a profitable and sustainable business. To respond to changes in the operational environment, transitioning toward power-based pricing is seen as a potential development direction. In this paper, we study various power-based distribution tariff (PBDT) structures and evaluate them from different viewpoints. To support the analysis, we provide a study where alternative tariff structures are analyzed based on data from two Finnish DSOs to investigate the impacts of the tariffs on the distribution fees of the customers and on the turnover of the DSO.**

***Index Terms*—Distribution network business, Demand response, Demand tariff, Network tariff, Power-based pricing**

I. INTRODUCTION

The reform concerning the distribution network tariffs of small customers has become a globally discussed topic in recent years. In many European countries, electricity distribution is legally unbundled from energy generation and transmission. In Finland, the electricity market opened for competition in 1995 and the small customers have been able to choose their energy retailer since 1997. The transmission and distribution networks remained as monopolies. This means that there is no one utility-like entity providing the customer with both the energy and its delivery. Although the unbundling was completed years ago, the distribution tariff structures applied for small customers are still those used during the pre-unbundling time.

There are many factors pushing the development of distribution network tariffs. Examples of future challenges for the Distribution System Operators (DSO) with respect to their tariffs, as described in, e.g., [1]–[6], are the increasing amount of small-scale energy production and the changes in consumption behavior due to demand response, energy efficiency solutions and the use of high-power appliances (e.g., ground-source heat pumps and electric vehicles). Although the large-scale tariff transition is yet to happen, there are signs of a rising interest regarding the reform. In Finland, for example, two DSOs have already started to apply a power-based distribution tariff (PBDT) consisting of a fixed monthly base charge, a volumetric charge and a power charge to a portion of their small customers (i.e., customers with higher consumption due to equipment such as electrical heating) [7]–[8].

This paper is a continuation of a long-term research work that aims to investigate the potential of applying power-based distribution tariffs for small customers in Finland. The paper fulfills the analyses and the results presented in, e.g., [9]–[12] by providing results that operate partly as the foundation to the conclusions presented in the earlier work. Although the case study presented in the paper is based on the Finnish electricity market environment, the results can be applied globally since the cost elements of distribution and challenges faced by the DSOs are similar to those in Finland.

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

1. What key factors promote the need for tariff reform?
2. What does power-based pricing mean?
3. What principles affect the selection of the PBDT structure?
4. What kinds of effects do various tariff structures have on the customers and on the turnover of the DSO?

The first question is answered through a brief description of the future challenges for the DSOs and their role in the electricity market. The second question is answered by describing what power-based pricing means and by providing examples of various distribution tariff structures based on power. The third question is addressed by discussing various properties that the tariff should include. The last question is answered through a case study in which data from two Finnish DSOs are applied and examples of the studied distribution tariff structures in two very different operational areas are provided. It must be emphasized that the results presented in this paper do not suggest what the tariff structure or what its price level should be in a real implementation. There are various factors that affect the tariff design in practice, not all of which have been considered in this paper.

The structure of the paper is as follows. In section two, various changes of the operational environment are described. The third section discusses power-based pricing as a potential development direction and presents alternative ways to include power in the small customer tariffs. Section four presents a case study investigating the impacts of different tariff structures. The results of the case study are presented in the fifth section, and the last two sections provide the discussion and the conclusions for the paper.

II. Changes in Operational Environment

In the future, DSOs are likely to face challenges regarding their pricing practices, especially in the case of small customers. Today in Finland, as in other European countries, these tariffs typically consist of two components: the fixed monthly base charge (€/month) and the volumetric charge for consumption (c/kWh). However, in some cases, the DSOs may apply separate charges for power (€/kW), typically based on contracted power rather than measured power [2]. The inconvenience with the present tariff structures is that the emphasis is on volumetric charges. When this is combined with the coming changes, the DSOs are pushed to develop their pricing practices. Additionally, the recent trend of raising the emphasis of the fixed charges is also problematic since it narrows the possibilities for customers to affect the magnitudes of their distribution fees.

A. *External challenges*

The present emphasis of the volumetric charges becomes a challenge especially when the amount of small-scale energy production at the customer site increases. Customers with their own energy production will pay smaller distribution fees. The volumetric charges thus create a problem for the DSO turnover formation, and the DSO has to compensate for the decrease by raising the price level of the tariffs. Customers who do not have their own production are left to pay more.

Another factor disputing the present pricing scheme is the overall transformation of the load profiles. Traditional energy efficiency and various new electrical equipment are consuming less energy, but on the other hand, appliances such as ground-source heat pumps have a high demand. Energy efficiency has aimed toward lower total energy consumption, which places pressure on the DSO turnover as the amount of small-scale energy production increases. The key cost driver for the DSO in the long term is based not on the annual energy consumption, but on the peak demand, which the electricity network has to be able to sustain.

B. *Internal challenges*

To enable the operation of various electricity market participants, the DSO has to provide a neutral and secure platform. The role of the DSO is to build, operate and maintain the grid and to do this; the income from distribution charges has to cover all the costs of the operation. Additionally, the DSO as a neutral market participant should not favor some customers through its pricing (e.g., a certain type of energy production). There are other effective instruments to boost distributed generation, e.g., energy-related taxes. In terms of the tariff structure, the key challenge is to design a tariff that treats customers equally, ensures stable turnover and does not set unfounded limits to or prevent the operation of other market participants.

III. Power-Based Pricing for Elecricity Distribution

To respond to the described changes and tasks, power-based pricing has been seen as a potential development direction [1]–[3]. The PBDT in the scope of this paper means a tariff structure that accounts for the power demand of the customer. By power, we mean the hourly average power, which in Finland is registered by the smart meters. The load data is remotely read from the meters by the DSOs and which is the present commercial unit used in the day-ahead electricity market as well as for the balance settlement. In the future, it is possible that the power on which the billing is based could be calculated, or even measured, from a shorter period.

A. *Principles for evaluating distribution tariff structures*

For a tariff structure to be successful, it has to comply with the general requirements. There are various pricing principles, which have been discussed in the literature, e.g., in [1], [2] and [13]. In the analysis, we have aimed to follow the general principles, but emphasize the present state and the practical viewpoints of tariff development. From the viewpoint of this paper, the evaluation of the studied tariff structures is based on the following main principles of

a. Cost-reflectivity
b. Equal treatment of customers
c. Resource efficiency
d. Intelligibility
e. Additivity
f. Feasibility of transition

By cost-reflectivity, we mean that the tariff structure should reflect the real costs of the service and that all costs related to the distribution have to be covered by them. A large portion of the distribution costs is fixed in the short-term, but over a longer period, it is dependent on the rated power (kW), which should be linked to the tariff accordingly.

Equal treatment of customers means that the tariff would treat customers the same way. Ideally, this means that no built-in mechanisms would exist to enable cross-subsidies between customers and that the magnitude of the distribution fee depends strongly on the consumption behaviors of the customers and their decisions.

Resource efficiency means that the tariff should encourage the customer toward both energy- and resource-efficient uses of electricity. This means that in addition to traditional energy efficiency, the aspect of electricity network capacity (i.e., the power) should also be included in the tariff.

Intelligibility means that the mechanism of what the distribution fee consists of is clear and relatively easy for the customer to understand. Additionally in this case, we do not refer to the number of tariff components, but rather to their core idea and mechanisms in forming the distribution fee.

By additivity, we mean that the distribution tariff structure would not be significantly different from those applied, e.g., by the energy retailers. Two very different tariff structures would weaken the intelligibility of the total electricity bill.

Feasibility of transition means that the transition should be possible without the customers having to make massive investments in various equipment, and the transition path should be as smooth and brief as possible. The feasibility of transition is one of the central points when considering tariff reform. The trend regarding DSO tariffs in Finland has been such that the emphasis has been gradually shifted to their fixed base charges [14]. However, this is not necessarily the best solution since the fixed charges lower the possibility for customers to affect the magnitude of their distribution fees, e.g., through energy-efficient solutions, and the motivation to do this would be lower. Figs. 1 and 2 present two hypothetical alternatives regarding the small customer tariff transition in a transition period of ten years from the total turnover point of view. In the figures, it is assumed that the target tariff consists of three components. In Fig. 1, the present trend is carried out until the change of tariff structure is performed overnight. In Fig. 2, the transition is started early on and the emphasis is shifted gradually to the power charges of the distribution tariffs. From the DSO point of view, the slower transition depicted in Fig. 2 would be a more favorable approach for both the DSO and their customers, as they would have more time to adapt to the changes.

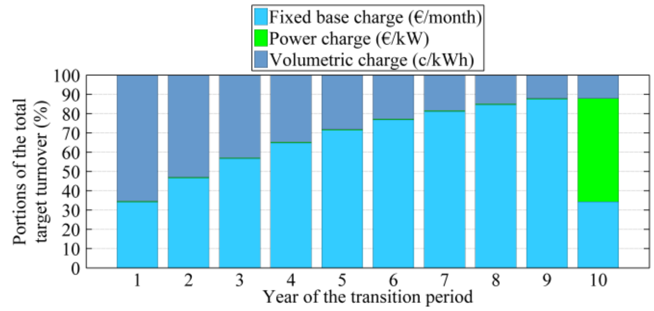

Figure 1. A hypothetical example of tariff transition scheduled for ten years continuing the present trend and ending in an overnight full-scale change of the small customer tariff structure.

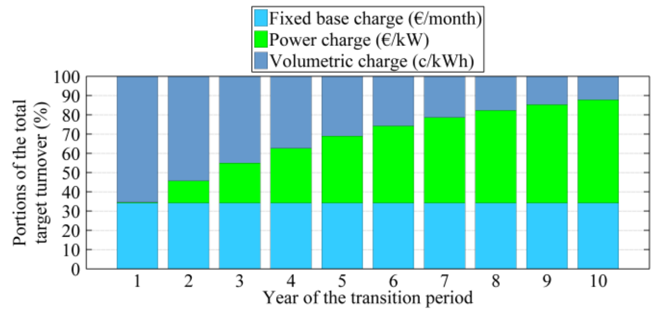

Figure 2. A hypothetical example of tariff transition scheduled for ten years where the small customer tariff structure is changed gradually.

B. *Power-based distribution tariff structures*

There are many variations of PBDTs. The power, as described in [13], can be taken into account in the distribution tariff structure, e.g., by

1. Linking the power to the size of the fixed monthly charge (€/month)
2. Linking the power to the volumetric charge (c/kWh)
3. Applying separate charges for power (€/kW).

Based on the above, we have studied four different tariff structures. The studied distribution tariff structures are

1. Power Limit Tariff (PLT)
2. Step Tariff (ST)
3. Threshold Power Tariff (TPT)
4. Power Tariff (PT).

The PLT, or so-called Power Band, as originally proposed, e.g., in [1] and [5], consists only of a power charge (€/kW), which could be based on a predefined limit (e.g., the historical peak hourly demand of the customer). In this case, the distribution fee is fixed for 12 months if the customer does not exceed the set limit. If the customer exceeds the limit, it would carry a sanction, e.g., the customer is moved to the next available power limit and will face a higher distribution fee, or a separate charge could be applied for the exceeding amount or the number of occasions.

The ST includes the same components as the present tariffs, the fixed monthly base charge (€/month) and the volumetric charge (c/kWh), and it has properties similar to the presently applied Time-of-Use (ToU) tariffs. The difference is that, unlike the time-of-day–dependent ToU tariff, the volumetric charge of the ST is linked to the level of consumption. This means that if the hourly power of the customer were to exceed a set limit (e.g., 5 kW), the volumetric charge for that hour would be higher than if the hourly power were lower than the limit. In the ST, the emphasis of the distribution fee is on the volumetric charge component.

The TPT comprises a fixed monthly base charge (€/month), a volumetric charge (c/kWh) and a separate power charge (€/kW), which is used if the monthly peak of the customer exceeds a set threshold value (e.g., 5 kW). If the peak hourly consumption of the month is lower than the set value, the tariff structure is the same as today.

The PT consists of a fixed monthly base charge (€/month), a volumetric charge (c/kWh), and a power charge (€/kW). In this paper, the power charge is based on the measured peak hourly power of each month.

C. *Compliance of the tariff options with the principles*

Each of the studied tariff options are evaluated based on the set of principles. Our analysis focuses on how the studied options execute the different principles, and based on the principles, the aim is to recognize the key strengths and weaknesses of the tariffs.

From a cost-reflectivity point of view, the PLT includes a clear link to power, and the stable turnover would be ensured through the fixed monthly charges. However, not all distribution costs, such as the costs of load losses and customer service, etc., are proportional to power. The ST links the power through the volumetric charge, but the cost-reflectivity is not so clear. Additionally, the volumetric charges do not ensure stable turnover. The TPT and the PT both include separate charges for power, which enable the costs to be distributed to different components accordingly. In the case of the TPT, the lack of a separate charge for the smallest customers would not increase the uncertainty from the turnover viewpoint since the customer responses to the present tariff structures are well known.

From the equality viewpoint, the PLT would result in the same distribution fees for customers of the same peak consumption but of a different overall load profile. A customer whose energy consumption is high but who has a flat profile would leave less available capacity for other users. A customer whose annual energy consumption is low but who has occasional peak load hours can be more likely to participate in demand response than the customer who is constantly using the maximum capacity. The occasional peak user would have to pay the same fee as a customer with a flat profile, and this could lead to cross-subsidies. In the aforementioned case of two different customers, the ST would result in higher distribution fees for the customer reserving most of the capacity and lower distribution fees for the customers with occasional consumption peaks. In this case, the ST could conversely result in too high a distribution fee for the flat user. The TPT and PT both include two separate consumption-related charges, which take into account both the energy and power aspects. When the distribution fee does not depend only on one factor, the cross-subsidies can be lower.

From the resource efficiency point of view, all the studied options are positive since they include a link to power through the consumption or the power charge. From a traditional energy efficiency point of view, the PLT would not encourage the customer to consume less energy per annum since there is no component steering to do so. On the other hand, in this case, the incentive to reduce overall energy consumption still exists in the tariffs of the energy retailers. Other studied PBDT options include features that steer the customer toward energy efficiency.

From the intelligibility point of view, the PLT would first appear as a very simple tariff structure. However, it is not so clear how the power limit would be set in practice and by whom. If it is left to customers, misunderstandings can happen. Additionally, it is not so clear how the exceeding of the limit would be handled. For example, in this case, the penalty would be a new, higher power limit, meaning raised distribution fees for a long period (e.g., 12 months). If the penalty were applied via separate charges, the price would be based on something concrete. Lastly, the absence of the traditional, well-known volumetric charge can prove difficult and may confuse the customers. These factors hinder the intelligibility of the PLT. In the case of the ST, the tariff structure consists of the same components as the present applied tariff options. What makes the ST unintelligible is the setting of the step and the mixing of power and energy. If the magnitude of the power (i.e., the step) were the same for every customer, it would be hard for the small customers with higher electricity use to accept the constant higher price for the volumetric part of the tariff. This relates to the aforementioned point made when the equality viewpoint was under discussion. The TPT also includes a predefined limit, but in this case, it could possibly even improve the intelligibility for the smallest customers. The PT does not include any limits other than what the technical maximum power of the connection of the customer has. The main hindering factor regarding the intelligibility of the TPT and the PT is the number of tariff components.

From the additivity point of view, the PLT is structurally different from, e.g., the present tariffs of energy retailers. In Finland, the customers have an option to select an energy tariff where the price differs hourly (spot-price in the day-ahead market). In this case, the customer could not gain all benefits from the fluctuation in price of electricity if the needed actions were to result in a higher power and exceeded the present power limit. However, when operating below the power limit, the customer can make actions to reduce the energy costs freely. In the case of ST, the tariff structure is dependent upon the power of every hour. In the case of dynamic tariff, the complexity rises when the decisions have to be made hourly to consider the effect of the distribution tariff. In the TPT, the structure of the tariff is the same as those of the energy retailers when the monthly peak consumption of the customer is lower than the set threshold limit. However, if the consumption is higher than the threshold value, there exists a clear unit price for the exceeding part. The same is included in the PT, the only difference being that there is no threshold value for the power. The prices for a certain amount of electricity and for the peak monthly demand are clear.

From the feasibility of a transition viewpoint, the PLT presents a challenge. If the whole distribution fee of the customer consists only of a power charge and there exists a predefined selection of power limits, it is not so clear how the transition to this kind of tariff structure could be made. The transition would either have to be made overnight, which would result in high bill impacts for some of the customers, or by using a temporary tariff to shift the emphasis from other tariff components to the power charge. The tariff consisting of the fewest components could actually prove quite challenging in practice. The ST, which includes the same components as the present tariffs, would also appear easy to implement. However, the change in how the volumetric charge operates would have to be made overnight. The DSOs could have difficulty explaining the rapid change to their customers. The TPT and the PT include an additional tariff component, which makes the tariff structure more versatile. However, the transition to these kinds of tariffs could actually be made slowly by increasing the emphasis of the power charges and observing their impacts.

Based on the aforementioned aspects, it appears that the PLT contains challenges regarding its implementation and rigidity. Pricing based solely on the annual maximum power could be difficult to justify to the customers. The ST also first appears as a simple structure, but there are problems regarding the definition of the steps and the equal treatment of different customers. The TPT and the PT are structurally more versatile, but the tariff structure in the end is quite transparent and the customer can affect the magnitude of the distribution fee through both the volumetric and power charges. It should be emphasized that the studied principles do not consider all possible aspects. To gain a more holistic view, we present a case study to investigate whether there are significant differences in the impacts of the tariffs.

IV. CASE STUDY

To investigate the impacts of various PBDT structures on the distribution fees of the customers and on the turnover of the DSO, we calculated tariffs based on the costs of the DSOs. The study involves two separate network areas operated by two Finnish DSOs.

A. *Initial data*

The two areas of the study are in different locations. Network I is situated in an urban area and the majority of the small customers are living in apartment buildings. Network II is situated in a mixed area (i.e., both an urban and a rural network) and there are more small customers who are living in detached houses. The studied networks cover only a fraction of the whole customer bases of the DSOs, but the study shows that power-based pricing can lead to significant differences in the prices between different operational environments. The key information regarding the studied network areas is shown in Table I.

B. *Power-based distribution network tariffs*

Based on the cost, network and consumption data, different PBDTs were calculated for the studied networks. For comparison, we also calculated the prices based on costs for the present tariff structures. This means that in the calculated present tariffs, the emphasis is on the fixed charges instead of the volumetric charges due to the application of the cost-causation principle. This would represent the situation over the last two years of the hypothetical transition path shown in Fig. 1. The tariffs involved in the study are formed based on the cost-causation principle, meaning that the costs are allocated to the customer groups based on their consumption in a similar manner to, e.g., [9]–[13]. This means that the tariffs are not designed to be optimal, but that they are based on costs with each studied tariff structure. In the calculation, the measured hourly consumption data from 2013 and 2014 was applied. The tariffs are formed for the year 2014 based on the consumption of the previous year, and the data from 2014 was used in the calculation as the realized consumption. Therefore, the customers are not expected to react to the new tariff by changing their consumption behaviors. The study shows the impacts of the PBDTs with regard to the present tariff structures. Customers who would be able to lower their peak demands can benefit from the novel tariff. However, this aspect is not analyzed in this paper.

To maximize the ability of the customer to affect the magnitude of the distribution fee, a large portion of the costs is allocated to the power-based charges. The power-based tariffs are presented in Tables II and III, which show that the price levels of the power-based tariff components vary significantly depending on whether the network is located in an urban or a mixed area. To clarify, the values presented in the tables are simplified so that in the case of the PLT, only the monthly charge for a power limit of 5 kW is shown. The PLT would have a selection of fixed power limits (e.g., steps every 5 kW), and a higher limit carries a higher fee.

TABLE I. KEY INFORMATION OF THE STUDIED NETWORKS

	Number of small customers	Target turnover (M€)	Average length of conductors per customer (m)
Network I	31,727	4.47	12
Network II	8,010	2.73	170

TABLE II. CALCULATED POWER-BASED DISTRIBUTION NETWORK TARIFF ALTERNATIVES FOR NETWORK SITUATED IN AN URBAN AREA

Network I – Urban area			
Tariff structure	**Fixed charge (€/month)**	**Volumetric charge (c/kWh)**	**Power charge (€/kW)**
Power Limit Tariff (5 kW)	9.72	-	-
Step Tariff (5 kW)	4.03	2.13 / 6.35	-
Threshold Power Tariff (5 kW)	9.30	0.53	2.95
Power Tariff	4.03	0.53	2.95

TABLE III. CALCULATED POWER-BASED DISTRIBUTION NETWORK TARIFF ALTERNATIVES FOR A NETWORK SITUATED IN A MIXED AREA

Network II – Mixed area			
Tariff structure	**Fixed charge (€/month)**	**Volumetric charge (c/kWh)**	**Power charge (€/kW)**
Power Limit Tariff (5 kW)	17.40	-	-
Step Tariff (5 kW)	3.82	3.30 / 6.80	-
Threshold Power Tariff (5 kW)	19.04	0.58	5.83
Power Tariff	3.82	0.58	5.83

V. RESULTS

The tariffs presented in Tables II and III affect the distribution fees, as presented in Figs. 3 and 4. It can be seen that the absolute changes in network I are relatively small. There is a clear peak around 10 €, which results mainly from the differences in the base charges of the TPT and the formed present tariff structures. Similar peaks occur in network II. The consumption in the mixed area varies more compared to the urban area, where the customers are more similar. This is one of the key factors behind the differences, together with the fact that in network II, the present tariff structure is mildly different due to the base charges being fuse-size dependent (i.e., a larger main fuse carries a higher fixed charge). There are customers who may experience higher changes than the ranges presented in the figures. These occur, e.g., when the customer has chosen a specific tariff some time in the past and the information has not been updated, although the consumption could have changed considerably.

In Table IV, the effects of each of the studied PBDT options on the annual turnover of the DSOs are presented. The table shows that the tariff change would not have resulted in high changes in the turnovers. The highest deviations occur with the PLT in both networks and with the ST in network II. From a transition viewpoint, stable turnover is critical for the DSOs to be willing to make the change.

VI. DISCUSSION

In tariff design, it is often difficult to produce exact and optimal results that account for all aspects involved. In the qualitative evaluation presented in this paper, certain principles were selected to assess the tariff structures, and the main emphasis was on the feasibility of the transition. Different conclusions can be reached if this focus changes. In the study, we investigated theoretical tariff price levels and rapid changes in tariff structure. This way, we can assess one of the worst-case scenarios, which could happen if the DSOs prolong the change and then suddenly decide to perform the transition without the customers reacting to the tariffs by changing their consumption behaviors. The ways that customers could affect the magnitudes of their distribution fees and their impacts are left for topics of further research.

VII. CONCLUSION

This paper discussed the development of the pricing of electricity distribution. We presented various alternative PBDT structures and analyzed each option from the viewpoints of different principles. To support the analysis, we presented a study where data from two Finnish DSOs was applied. Based on the results of the analysis and the case study, it appears that the studied Power Tariff and the slightly more versatile Threshold Power Tariff would appear as the most attractive candidates for the future tariff of small customers. This conclusion is made by emphasizing the feasibility of the transition viewpoint. The results presented in this paper do not suggest what the tariff structure or the price levels should be in a real implementation. Various factors affect the practical tariff design and there is no universal one-size-fits-all solution for electricity distribution pricing.

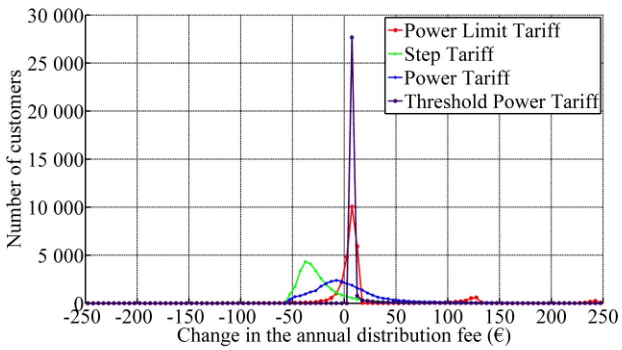

Figure 3. Distribution of changes in the annual distribution fees for the majority of small customers (i.e., over 94%) when each alternative tariff option is compared to the present tariff structure in network I.

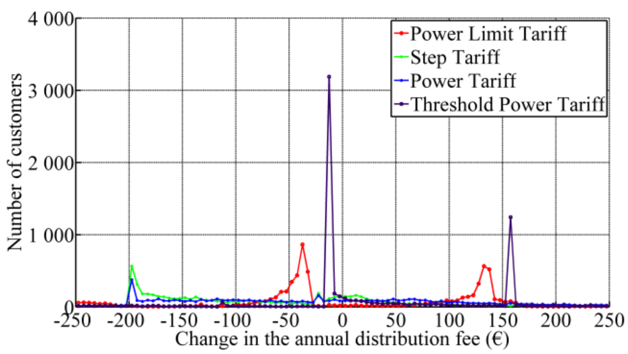

Figure 4. Distribution of changes in the annual distribution fees for the majority of small customers (i.e., over 84%) when each alternative tariff option is compared to the present tariff structure in network II.

TABLE IV. DIFFERENCES IN ALTERNATIVE TARIFF STRUCTURES WITH RESPECT TO TARGET TURNOVERS IN THE STUDIED NETWORKS

Tariff structure	**Difference in target turnover (%) Network I / Network II**
Present tariff structures	-0.29 / 0.72
Power Limit Tariff	-1.36 / -1.11
Step Tariff	-0.34 / -1.73
Threshold Power Tariff	-0.09 / -0.66
Power Tariff	0.40 / 0.68

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