IMPLEMENTATION POSSIBILITIES OF POWER-BASED DISTRIBUTION TARIFF BY USING SMART METERING TECHNOLOGY

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ABSTRACT

This paper discusses on the implementation possibilities of distribution tariffs that include a separate demand (i.e. power) component for small customers by taking use of the present, and still developing, smart metering technology. Power-based distribution tariffs offer the customers effective price signals and better possibilities to affect to the size of their distribution fees through their own actions. The use of demand based components in the tariff structures also reflects the actual cost structure of the Distribution System Operator (DSO) and could make the pricing of the DSOs more just and transparent. In the paper, the possibility of limiting the yearly peak hourly power demand of the customer with the software fuse functionality of the smart meters is in a key role when different ways of implementing power based distribution tariff are studied. The paper also provides information about results of a questionnaire made to smart metering technology vendors about the present state and technological possibilities of the smart meters e.g. in the case of load control possibilities.

INTRODUCTION

The discussion involving electricity distribution pricing development has been going on for many years and in recent years it has been on the rise. One big driver behind the growing discussion in European countries, such as Finland, has been the wide roll-out of smart meters. The old energy consumption meters have been replaced by smart meters, which have also other functionalities in addition to just measuring cumulative energy consumption. The smart meters have also e.g. the capability to connect or disconnect loads which is useful in implementing alternative distribution tariffs. Especially the so called *software fuse* functionality of the smart meters is in the essential focus of this paper. With the software fuse functionality, certain pre-defined hourly power limits could be programmed to the smart meter to use the limit as a threshold to control loads and thus making it possible to implement, in practice, tariffs that have a separate power component (later power-based tariff) for small customers. Note that in the scope of this paper, the software fuse is linked to the *hourly power demand* (kW) rather than on current (A), which the fuse as a traditional protection device is based on.

In Finland, the legislation demands that the pricing of electricity distribution has to be reasonable and non-discriminative. This guides the pricing to follow the matching principle leading towards cost-causation where the customers would pay only the costs that are caused by them and the cross-subsidies between customers of different sizes would be minimized. This paper does not cover the issues related to the exact process of the pricing of electricity distribution but more on the general way of implementing power-based distribution tariff in practice. The matters concerning the more thorough pricing process have been previously discussed in e.g. [1].

In this paper, the focus is on the Finnish electricity market and regulatory framework and it is organized as follows. First the present state of distribution tariffs in Finland is introduced. In the second section, some major drivers behind the distribution pricing development needs are discussed. In the third section, general idea of the power-based distribution tariff is discussed. In the fourth section, present state of the smart metering infrastructure in Finland is introduced and results of a questionnaire made to smart metering technology vendors are presented. In the fifth section, different optional solutions to implement power-based distribution tariff are examined by a simple case study.

PRESENT STATE OF ELECTRICITY DISTRIBUTION TARIFFS IN FINLAND

In Finland, the customers have the right to select their distribution tariff from the price list of the DSO. The present tariff options aimed for the small customers are the following. For relatively small customers (e.g. yearly energy consumption less than 10 MWh), the so called *General tariff* is offered. The General tariff consists of a fixed charge component (€/month) and a volumetric energy charge (cent/kWh), which is the same for every hour of the year.

For larger customers (e.g. customers with electric heating), *Time-of-Use (TOU) tariffs* are usually offered. In the TOU tariffs, the energy charge varies with time. In the so-called *Night-time tariff*, the energy charge is more expensive during the days compared to the night-time 22:00-07:00. In the so-called *Seasonal tariff*, the energy charge is more expensive during winter working days between 07:00-22:00 compared to other time.

In the aforementioned tariff options aimed for small customers, the basic charges are either the same for every customer of the same tariff or the amount of the charge can depend on the connection size (i.e. fuse size) of the customer.

For large customers (e.g. industrial or commercial customers), the so called *power tariffs* (Low voltage (LV) or medium voltage (MV) power tariff) are offered. In these cases, the tariffs consist of a fixed charge, a volumetric energy charge and a separate demand charge (€/kW) for active power. The amount of the customer-specific demand fee depends on either a single measured power or on the average of some number of measured powers. In some cases the power tariffs also have a separate price component for reactive power.

DRIVERS FOR DEVELOPING NEW DISTRIBUTION TARIFF STRUCTURES

Different factors create pressure to develop the electricity distribution pricing. With present distribution tariff structures being energy dependent, the sustainability of the electricity distribution business might be threatened in the future. If e.g. the amount of small scale distributed generation in the grid would massively increase, it could lead to a situation where the energy flowing through the grid would be lower. Smaller amount of energy distributed through the grid combined with energy dependent pricing would lead to smaller turnover. [2] With present price structures, the solution for this problem is either to raise the tariff rates (basic or energy charges) or to develop the pricing (i.e. use more flexible tariff structures). If the present tariff levels would be raised, it could be problematic since the tariffs would favor the customers, who have their own generation and the customers, who do not have generation, would face higher distribution fees.

In addition to the aforementioned points, there are also other factors pushing to develop the pricing. E.g. in Finland, the role of security of supply is in a key role in network business regulation. The DSOs are also responsible for operating and developing the grid in the future which means that the investment needs of the aging distribution grid are more likely to rise than decrease. [3] Thus one aim is to use network capacity as effectively as possible. The EU's Energy Efficiency Directive (2012/27/EU) pushes development towards total energy efficiency and the DSO's tariffs should not be an obstacle in achieving these goals. [4]

POWER-BASED DISTRIBUTION TARIFF

As an alternative for present tariff structures offered to the small customers, a tariff that has a power demand dependency is discussed in this section. The power-based tariff is a tariff structure where there is, with or instead of the present fixed and volumetric component, a demand-based component for active power (i.e. power charge component).

The power-based tariff structure differs from the present tariff structures of small customers, where the costs of the DSO related to power demand are usually included in the tariffs' basic charges. As mentioned above, the basic charges are the same for all customers of the same tariff group or they can depend on the fuse size of the customer inside the same tariff. However, having the same fixed charge for different sized customers inside the same tariff group results in cross-subsidies between smaller and larger customers (e.g. for 3x25 A customers, the measured peak hourly demands can vary from values close to zero all the way to values higher than 17 kW, yet they pay the same basic charge). The network should though be rated based on the peak demand. The smaller customers might have to pay for the costs caused by the larger customers or vice versa. This is because there is no straightforward mechanism for individual customers to affect to the size of their basic charges.

In tariffs that have a power demand component, the customer has a chance to affect to one's distribution fee more efficiently. Power-based distribution tariff would also realize the matching principle (i.e. cost-causative pricing) better, since the tariff structure reflects the DSO's cost structure and the customers pay for their use of the grid in a more precise manner.

The power-based tariff can also mean that the distribution tariff could be thought as a "power band" as presented in [5]. In this tariff, the customer buys a certain amount of demand capacity from the DSO and pays a monthly fee for it. This idea is moderately similar with e.g. the pricing of internet broadband connections in Finland.

Power-based distribution tariffs are not yet used for small customers in Finland but the discussion is ongoing. One of the possible reasons for the DSOs to not have implemented them could be that there is little practical information available about their effects e.g. the changes in the consumption behaviour of the customers or financial issues.

SMART METERING

In 2009 the Finnish Government passed the act 66/2009 concerning electricity markets [6]. The act states that at least 80 % of the customers of each DSO must have smart metering implemented by the end of year 2013. This requirement for smart metering also included that the hourly consumption data is to be collected and the possibility of controlling the customer load must be included in the meter. No detailed requirements for load controlling possibility were introduced in the act.

Smart metering can be discussed in terms of what it offers to the DSO, TSO, customer and the energy retailer. E.g. low voltage network management, discussed in [7], can be additional value to DSO. Additional value is needed as smart metering increase the metering costs [8]. Concept of business model can be used to have overall view of smart metering [9].

Demand Response

Demand response (DR) is a concept often presented when discussing about electricity grids. Demand response means that some market actor or other party offers some incentive for electricity customers to change their electricity consumption behavior so that both the incentive offering party and the customers benefit from the change. Different parties can be electricity retailers, transmission system operator (TSO) and DSOs. Electricity retailers could use customers' flexibility to optimize the retailer's electricity trade in the wholesale market. TSO could encourage customers to use their loads in different kinds of reserve markets. DSOs could take advantage of customers' controllable loads in order to e.g. reduce load peaks in the distribution networks for different purposes. In this paper, DSO driven DR is investigated which would be made within one hour long time windows via smart meters.

Software fuse functionality

The software fuse is considered as a function either to measure and log the exceeding of a set hourly power limit or to use it as a threshold to disconnect loads that can be controlled. Considering this paper and the tariff design, the time resolution is one hour. In practice, the load controls would be made intra-hour but the detailed methods to control loads are not in the scope of this text and are subject of future studies.

If the use of e.g. electrical heater or storage water heater could be controlled in a way that it would not be on at the same time as the customer's other appliances, the peak hourly power could be contained under a set limit by shifting the heating demand.

State of smart metering from DR viewpoint

As part of this study, a questionnaire survey for Finnish smart metering vendors was conducted. Based on that and the results of similar questionnaire for DSO´s main functionality and availability of DR solutions in Finnish smart metering systems [10] is studied. These results are presented in table 1. In these results, the software fuse functionality is studied as one measure for DR. It is looked from the load control relays and breaker device point of view. Note that minority of smart meters in Finland has a breaker device (i.e. an internal or additional device which can be used to connect or to disconnect the customer to or from the electricity grid) and exact coverage of that is not studied in here. Meters typically include two relays. One is used based on timing, especially so that load is connected during night-time due to TOU tariff. Load control possibility set by [6] is arranged by adding other relay or interface for external control, and it is called here freely controllable relay. One limitation concerning the results is that utilizing different function may require update to the meter. However, according to results of questionnaire this update can be done remotely.

__Table 1__. Functionality of smart metering systems in Finland from DR point of view.

Functionality	Coverage (%) in Finland
Relay that can be commanded freely (not associated with any timing calendar)	74,00 %
Meter includes functionality that allows to detect load current/power (instantaneous measurement to support the software fuse functionality)	100,00 %
Exceeding for current/power threshold can be saved into log files (logging software fuse).	63,00 %
It is possible to control breaker device in meter using exceeding of set threshold (controlling software fuse) if such a device exists.	100,00 %
Load control relay (relay with timing calendar) can be controlled using exceeding of set threshold.	47,00 %
Freely controllable relay (not associated with any timing calendar) can be controlled using exceeding of set threshold	47,00 %
Calendar timing in relay can be adjusted remotely.	71,00 %
Relay with timing calendar can also be controlled remotely so that timing commands are changed or overridden.	45,00 %
Meter has interface for energy consumption data for external automation device.	50,00 %
Meter has frequency measuring capability.	50,00 %
Frequency measurement can be used for controlling the relays in the meter.	21,00 %
Frequency measurement can be used for controlling the breaker device in meter.	21,00 %

DIFFERENT OPTIONAL SOLUTIONS FOR IMPLEMENTING POWER-BASED TARIFF

The implementation possibilities of power-based distribution tariff are studied in this section. The data used in the calculation is based on a part of a certain Finnish DSO's customer data covering the information of 5 585 customers that have the maximum fuse size of 3x63 A. The idea of this study is to examine the financial effects of implementing a power-based tariff of the same structure than the LV or MV power tariff discussed earlier to small customers.

Inside the customer base used in this case study, there are 1 619 customers, who are classified as customers with some kind of electrical heating devices. In this study, these customers are seen as potential customers who could have such applications that could be controlled by the smart meter.

Case study

As a base case, distribution fees are calculated for each customer by using the DSO's present tariffs to find the customer specific minimum distribution fees. The total turnover collected with the original distribution fees is 2 612 832 € (incl. VAT). The portions of the basic and energy charges from the total turnover are 47 % and 53 % respectively.

Use of hourly-based measurements

The power-based distribution tariff is determined based on the turnover of present tariffs. The tariff is formed so that from the total turnover, 10 % is gathered in a form of basic charges, 53 % is gathered by energy charges and the remaining 37 % is covered with power charges. To form the yearly power charges, sum of individual customers' yearly peak hourly powers is calculated from the hourly measurements of one year. The required turnover from power charges is 968 258 € and the sum of customer specific yearly peak hourly powers is 37 359 kW. The yearly power charge is 25.92 €/kW.

If the power-based tariff would be implemented by just taking use of the hourly measurement data in the centralized measurement database level, changing the tariff structure and assuming that every customer would select the power tariff, the customers' distribution fees would naturally face changes. The distribution of changes in customer specific distribution fees compared to the original distribution fees and the mean change are depicted in figure 1 (*no actions*). The changes in the distribution fees range from -83 % to 162 % the mean change being 0.87 %. The transition from fuse-based tariffs to power-based tariffs also affects to the way how the total turnover is formed with different tariff price components compared to the original tariffs.

Since the tariff components are based on the turnover demand of the DSO and no change in the customer specific yearly peak hourly powers is assumed to take place, the total turnover of the DSO remains unchanged.

Use of software fuse functionality

If the same power-based tariff would be implemented by taking use of the software fuse functionality of the smart meters, some changes would happen compared to the previous case. The customer specific pre-defined hourly power limits would prevent some of the customer's appliances to work simultaneously in a way that the limit would not be exceeded. A reduction in the customer-specific yearly peak hourly power could therefore be achieved by setting a stricter limit for hourly power.

Accurate customer-specific peak hourly power reduction potential requires a more thorough study and it is not done in this paper. However, a relative reduction in the hourly peak powers is assumed for those 1619 customers that are classified to be customers with different electrical heating solutions according to the customer information. A drop of arbitrarily selected values of 5 %, 10 %, and 20 % in customer specific yearly peak hourly powers was studied. The distribution of customer specific changes in yearly distribution fees and the mean changes are depicted in figure 1.

The changes in the distribution fees range from -83 % to 162 % the mean changes are 0.31 %, -0.24 % and -1.35 % respectively. The turnover portions gathered with different charges are shown in table 2.

Table 2. *Charge component specific turnover portions from the total turnover with different relative reductions in customer-specific yearly peak hourly powers.*

Reduction in power	Basic charge (%)	Power charge (%)	Energy charge (%)
5 %	10	37	53
10 %	10	36	54
20 %	10	35	55

The reductions in the turnover of the DSO, due to reduction in power, are 20 206 €, 40 412 € and 80 824 € respectively. If the turnover were to remain unchanged, the power charges would have to be raised to 26.47 /€/kW, 27.05 €/kW and 28.28 €/kW respectively.

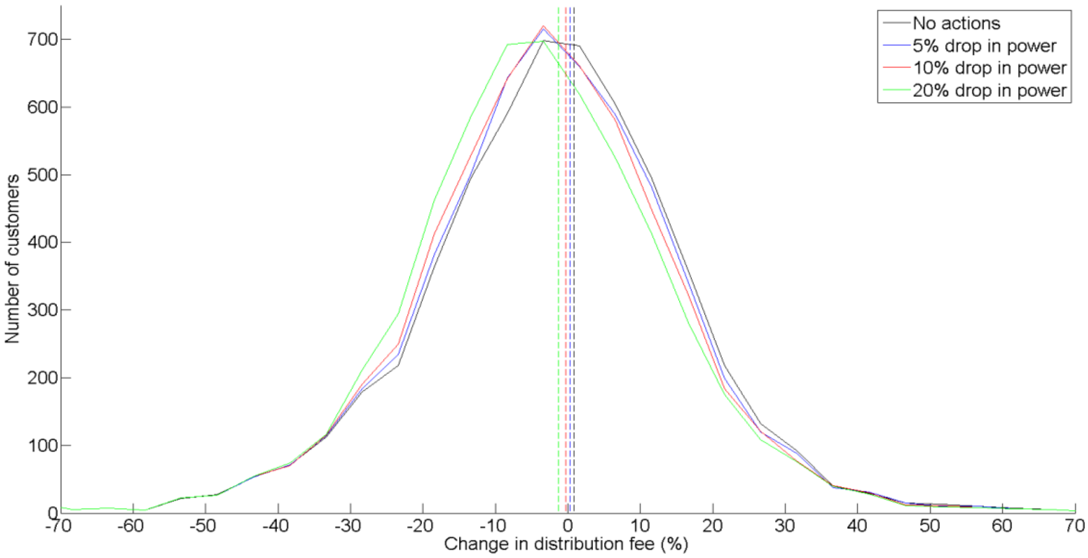

Figure 1. *Distribution of changes in the yearly distribution fees of the customers. Mean changes are depicted with dashed lines.*

DISCUSSION

The implementation of power-based distribution tariff for small customers has both strengths and weaknesses. From the viewpoint of different market operators, some of these features can be described as follows. From the viewpoint of the customer the main strength of the power-based tariff is that it gives the customer more ways to affect to the size of one's distribution fee. It also reduces cross-subsidies between different sized customers of the same tariff. The main downsides of the power-based tariff are the added complexity to the tariff structure compared to present tariffs and that some customers would naturally face larger distribution fees if the power-based tariff would be implemented as straightforwardly as it is done in the case study.

From the viewpoint of the DSO, the power-based tariff could make the DSO's pricing more just and transparent. The tariff structure would reflect the DSO's cost structure in a more precise way compared to the present fuse-based tariffs. If individual customers would restrict their yearly peak hourly power with the use of software fuse functionality and the unwanted side effects, such as after peaks in the network caused by the shifted consumption, could be avoided, the utilization rate of the grid could be higher than today. The network impacts are not studied in this paper and they require a more thorough examination. As the downsides of power-based tariff, the tariff design complexity increases and the DSO's turnover from the capacity related fees would not be as even as it is with present basic charges due to changing power charges.

From the societal point of view, the effects of power-based tariff could have benefits when implemented in a suitable way. The power-based tariff, together with market price based energy tariffs, encourage the customer towards total energy efficiency.

There are some practical challenges in implementing of power-based distribution tariff. One of the technical challenges of doing controls by using the software fuse functionality is that the meters require an update.

It should be noted that the tariff design depends on the accuracy of customer data and hourly measurements. It is not uncommon for the customer information system to have imperfect information about e.g. the customer classes and other relevant information.

It is also worth discussing whether the smart meter is the correct device to use for load controls. Instead of controls made with the smart meter's software fuse functionality, different systems such as Home Energy Management System (HEMS) could be used in order to optimize the whole electricity bill of the customer, which consists of both the DSO's and the energy retailer's tariffs.

CONCLUSION

In the paper, the possibilities of implementing power-based distribution tariff for small customer is discussed. The software fuse functionality of the smart meters can be in a key role when different ways of limiting the customer's yearly peak hourly power are studied. With present smart metering infrastructure, the implementation of power-based distribution tariff for small customers is possible, but to enable load reduction through the software fuse functionality, some effort e.g. meter updates are required.

For future studies, the load control potential should be examined in more detailed and precise manner. Also, the energy retailer's tariffs and network impacts should be included in the future studies.

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