MANAGING IMPACTS OF DISTRIBUTED ENERGY RESOURCES AND DEMAND RESPONSE BY TARIFF PLANNING

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ABSTRACT

Operational environment of the electricity distribution is changing rapidly. This is due to increasing energy efficiency, smart grids, distributed generation, demand response and energy storages, for instance. Impacts of the new operational environment are significant. This paper studies how to manage impacts of distributed energy resources and demand response on distribution business in future. The study is based on the reviews of smart grid and energy efficiency trends. The paper proves that many changes will appear, but changes on distribution business can be managed by appropriate tariff planning. Energy based tariffs will face remarkable challenges in future from the distribution business perspective and the present distribution tariff structures have to be modified, if distribution system operators (DSO) want to maintain revenue at the same level as today. It is concluded that power based tariff seems to be the best solution for DSO tariff structure.

1 INTRODUCTION

Distributed energy resources (DER) and demand response (DR) have effects on electrical power and the energy transmitted through distribution network, which again have short- and long-term influences on the costs and revenue of the network business. Effects of DER and DR are mainly energy based. For instance, distributed solar and wind generations can typically decrease energy demand. During the winter time, effects on power are very low. In addition to distributed generation (DG), energy efficiency and high level of the price of electricity can decrease energy consumption remarkably in future. DSO's tariff structure is typically based on energy also. The consequence is that this will have straight impacts on electricity distribution companies' revenue.

The dimensioning of the grid components is based on the peak power. Investments and financing costs are based on the power demand. Operational costs e.g. operation, maintenance, and repair are based on the size and type of the network, which means that there is not direct dependency on the energy or power demand. Losses are mainly based on the amount of the delivered energy. Metering and billing are based on the amount of the customers. Administration costs are mostly based on the size of the company. Transmission network fees depend on the tariff structure of the TSO, e.g. in Finland, they are energy based. However, the costs of the TSO are mainly power based. The majority of the DSOs' costs are based on power demand, while incomes are mostly based on energy demand.

Smart grid environment with smart metering can provide the base for a new type of energy pricing and create completely new operational environment for electricity distribution. EU and Finnish legislation set some limitation on tariff structures. Economic regulation of electricity distribution sector limits the revenue of the distribution companies, but DSOs can decide pricing methodology mainly on their own. New tariff planning methods for electricity distribution business will be discussed later. This paper also includes introduction to the different tariff structures and analysis of their suitability for the electricity distribution companies, as well as their impacts on the energy efficiency incentives and demand side management (DSM). The final conclusion of this paper defines the best solution for DSOs' tariff structure.

The structure of the paper is the following. Chapter 2 introduces basic smart grid environment, which includes e.g. interactive customer and energy storages. Chapter 3 reviews the impacts of the distributed energy resources on the electricity distribution business. Demands for tariff structure are also discussed. In Chapter 4, demand response impact is analyzed by the literature survey. Different tariff structures are presented in Chapter 5. It is also discussed, which pricing methodology would be the best solution. Conclusions are drawn in the last chapter.

2 OPPORTUNITIES AND LIMITATIONS IN TARIFF PLANNING

The pressures in energy saving actions and climate change have set opportunities and limitations. In electricity distribution business the most promising development trend is smart grid, including smart metering. Smart meters can provide the opportunity for DSOs to introduce totally new tariff structures. On the other hand, tariff structure options have some limitations by the EU and Finnish legislation.

2.1 Present tariff structure

The proportion of electricity distribution of a residential customer's total electricity bill is about 25 %, as presented in the Fig. 2. On the other hand, 65 % of a customer's electricity bill is comprised of energy-based charges. [1] This guarantees that the billing encourages the customers to reduce their use of energy even, if the distribution network tariff scheme is based on a fixed fee only. Traditional tariff structure of a Finnish DSO is energy based tariff combined with a fixed fee, which is typically dependent on the size of the main fuse (cents/kWh + €/month). The proportion of the fixed and energy based fees vary between the companies and customer types. Small-scale consumers' typical proportion of fixed fee is about 30-60 % in DSO tariffs.

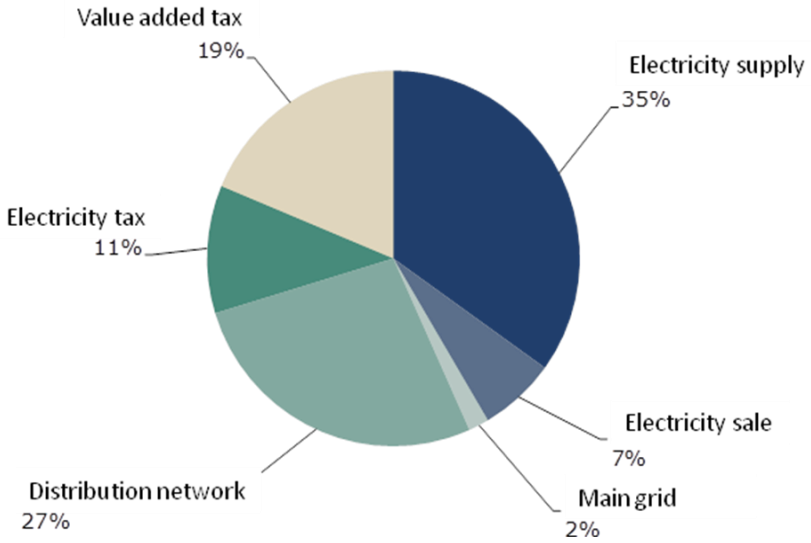

Fig. 1. Electricity price of household customer 1.2.2012. [1]

The Finnish Energy Market Authority has made a report of distribution tariffs. The research report shows that proportion of fixed fees has increased significantly during the last 10 years. [2] This tells developing needs of tariff structure. An increasing amount of fixed fee proportion improves predictability of distribution incomes. This is partly due to changing trends in electricity usage, when amount of distributed energy is varying. The outdoor temperature is another reason for the variation of energy consumption.

2.2 Smart grid

The common view is that smart grid will change electricity distribution environment. Smart grid can include energy storages, small-scale distributed generation, different kind of controllable loads and information, e.g. price signals. Smart grid includes a lot of opportunities for tariff planning. For example, interactive customer gateway and smart metering will create the base for the smart grid environment.

Interactive customer gateway will be based on smart meters, which provide e.g. information on consumption to customer and DSO. Smart meters are currently being installed widely and they provide functionalities, which support the development of the tariff structures. For instance, in Finland at least 80 % of the customers will have automatic meter reading (AMR) at the end of the year 2013 [3]. Energy measurements have to be based on hourly measurements and DSOs are obligated to read meters once a day. Energy meters have to be able to receive, transmit and execute load control commands.

Energy storages' role in the electricity distribution is insignificant at the present. In future, the situation can be different if residential customers have private storages, mostly in electric vehicles. Storages can steady power peaks and solve blackout situations. End-user customers have a lot of loads, which are time and size dependent. These loads are sometimes difficult for DSOs. With DSM and DR troubled power peaks could be avoided, when different kind of information and signals are in a major role. Examples of information signals are customers'

energy and power consumption, faults, capacity control information, temperature, electricity prices and control signals.

Small-scale distributed generation will decrease the amount of delivered energy, which is transmitted through distribution network, radically. Wind and solar power will have challenges in northern circumstances. During the winter time, wind or solar plants cannot produce all the electricity that is needed. Cold and dark weather decrease potential from small-scale renewable energy production. Instead, during spring, summer and autumn electricity demand from public grid could decrease significantly.

2.3 Decrees

Concerns of climate change and fossil fuel depletion have had effects on energy sector. Many energy efficiency decrees have been given, and they include inputs for the electricity pricing. In the area of Europe, the EU legislation has set many targets for energy efficiency. Many directives and decrees also regulate energy pricing. The most relevant EU directive is 2006/32/EC, which says: *"Member States shall ensure the removal of those incentives in transmission and distribution tariffs that unnecessarily increase the volume of distributed or transmitted energy."* [4]

In addition to EU directives, relevant for this issue are also Finnish electricity market law (386/1995), the law of energy efficiency services (1211/2009) and decree of electricity delivery and metering (66/2009) – set some guidelines for electricity pricing in Finland. The most important is the Finnish electricity market law, which says that distribution pricing has to be moderate. Also, the law says that distribution prices are not allowed to depend on where the customer's geographical location in distribution network is (spot pricing).

3 DISTRIBUTED ENERGY RESOURCES EFFECTS ON TARIFF PLANNING

Big changes are happening in electricity consumption. Typically, energy efficiency targets, electricity price and new attitudes to life create new trends in electricity usage. Especially households put a lot of effort to reducing electricity consumption. Smart grid environment and smart customer will probably change consumption from earlier. During the last 5 years, national electrical energy consumption has not increased in Finland. [5] This is partly due to economic situation. However, if customers' bills are based on consumed energy and DSOs' costs are staying at the same level, DSOs are facing challenging conditions.

Increasing electricity price have an influence on consumer behavior. Energy efficiency standards have improved electrical devices. On the other hand, number of the electrical devices has grown, which increases electricity consumption. Normally energy efficiency actions decrease electricity consumption. Less energy consuming electrical devices, e.g. LED-lamps, heat pumps, customers' own electricity production and energy storages can decrease electricity usage substantially. Some exceptions exist. One example is heat pumps in non-electric heating buildings. In these cases electricity consumption will increase. Generally the demand of electrical energy will decrease as the number of heat pumps increase. One scenario predicts that

in typical Finnish rural distribution company, increasing the amount of the heat pumps may decrease the annual revenue of the network business by 5 % by the year 2020, if present tariff structure is applied. [6] This is a short-term influence of DER. In a long-term scenario residential customers' electricity usage will increase, if electric vehicles become common.

Another thing, that may have large-scale impacts on distributed energy, is small-scale distributed generation. For example, in Germany solar and wind power have increased fast. [7] The main conclusion is that energy demand will decrease but demanded power during winter time will probably stay at the same level.

Most challenging for a DSO are such actions, which decrease the amount of the delivered energy more than power demand. In such case, the revenues of the DSO will decrease, while costs remain the same or even increase. To ensure that incomes will cover the costs, more cost reflective tariff structures must be developed. Changes in the tariff structures are needed, because electricity distribution companies are falling into changing conditions, as presented in the Fig. 2.

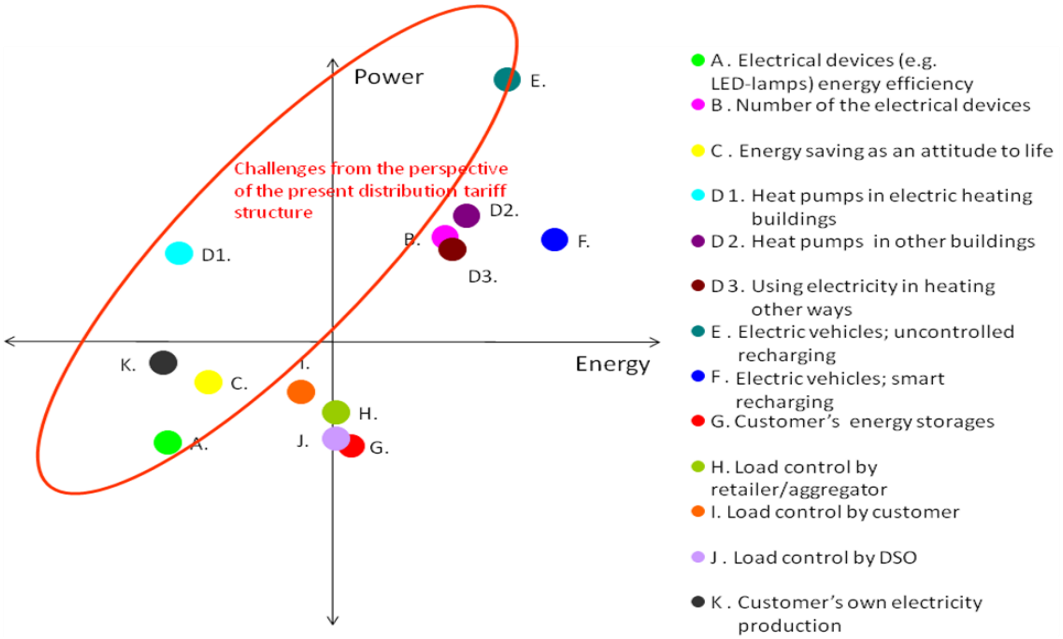

Fig. 2. Changes in electrical energy and power transmitted through electricity distribution network. [8]

DSOs will probably face big changes in the distributed energy and power. Total effects on DSO's revenue can be either positive or negative from the perspective of the distribution companies. From this perspective, the present tariff structure isn't competitive anymore. Furthermore, such development does not affect the costs of the company. From the viewpoint of DSO, such development means that incomes do not cover the costs, which jeopardize the business, although such development is highly desirable, since it increases the energy efficiency in the heating of the buildings.

4 EFFECTS OF DEMAND RESPONSE ON TARIFF PLANNING

For the whole energy system, it is essential, that distribution and retail tariffs together create incentives to act so that economic benefit maximizes. When optimizing generation and network capacity, and at the same time increasing of renewable energy, e.g. solar power, the demand response is in the key role. In practise, demand response can be implemented automatically or manually by customer. Also load control is an option. Load controller can be DSO, aggregator or retailer. [9]

The retailer generally has the best ability to explore and utilize the business potential of customer load control [10]. If someone else is the DSM operator, such as the local DSO, troubles will appear. If DSO controls the loads of the customers based on its own interests, the retailer's power balance between electricity procurements/production and consumption/sales can be disrupted. Unexpected changes in the retailer's power balance, could seriously damage the retailer's business. Therefore, retailers have to be in charge of load controls. [11]

Retailer's load control has also in some cases negative effects on distribution network. For instance, if retailer has optimized demand response with his target, it may create power peaks in distribution network. [12] This means that DSO's costs increase and electricity retailer gets financial benefit from load controls. [9]

5 TARIFF STRUCTURE ALTERNATIVES

This paper has proved that there are many reasons, why present tariff structure needs developing. Basically, electricity distribution can be priced in many different ways. When considering the best tariff alternative, the main requirements are especially spot pricing, cost-reflectivity and understandability. Fig. 3 presents basic requirements for the demanded tariff structure.

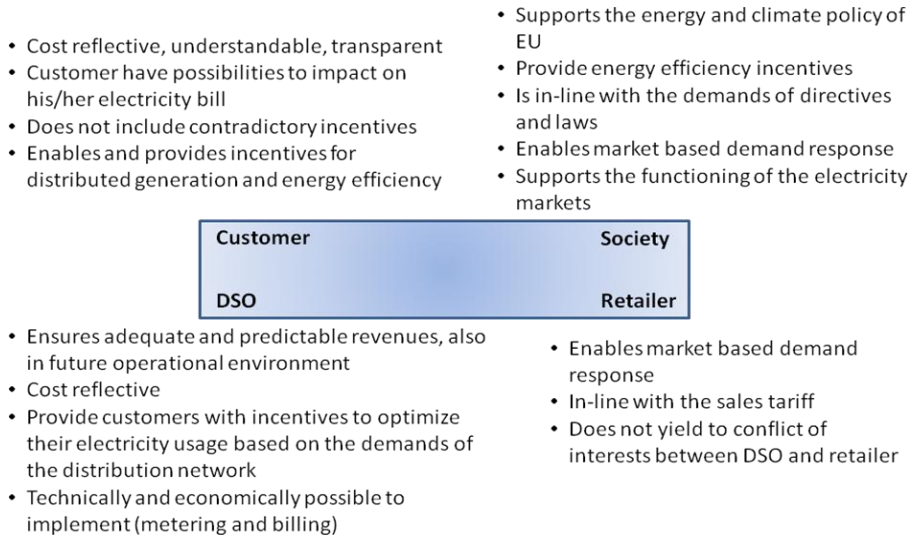

Fig. 3. Basic requirements for the distribution tariff. [9]

In practice, conceivable alternatives are restricted to few tariffs, which can be used individually or by putting together different option, like present tariffs energy + fixed fee. These alternatives are compared with the basic requirements and demands for the suitable tariff option. In the next paragraphs some tariff structure alternatives are presented.

5.1 Fixed fee

In this tariff option the basic ideology is that fixed fee is based on the size of main fuse. Energy fee would be removed from the existing tariff structure. DSO's revenue should stay at the same level, and that's why fixed fee should be higher than today.

This kind of tariff structure would be understandable for the customers and for the DSOs business operations it would be more predictable and cost-reflective. Tariff would not include contradictory incentives with sale tariffs and it also enables market-based demand response. From the point of DSO's network, this option includes only incentive to optimize customer's main fuse. Generally, there are very limited number of main fuses in use, for example small-scale customers' have typically main fuses of 3x25 A or 3x35 A. In this case peak power is limited only with the main fuses and tariff does not include any other incentives to optimize power consumption. Sale tariffs provide incentives to optimize energy usage.

Recent trend has been increasing the fixed tariff component. The final phase of this development would be a fixed fee alone and energy component would totally be removed. Fixed fee would guarantee DSOs' predictable and firm revenue in changing operational environment. A negative thing in this kind of tariff is that the customer cannot control his own electricity bill and the tariff would not motivate to use electricity efficiently. Tariff structure, which would merely consist of fixed fee, does not fulfill represented requirements.

5.2 Energy based tariff

A completely opposite alternative to the present trend would be purely energy based tariff. A share of energy based fee in distribution pricing has been decreasing, which indicates the problems in energy based pricing from the DSO's perspective. Only a small part of DSO's costs depend on the amount of distributed energy. Therefore solely energy based pricing would be less cost-reflective than the present pricing (fixed fee + energy). Predictability of DSO's revenue would fall off, because distribution incomes would be directly dependent on the amount of delivered energy. In this case, e.g. outdoor temperature would have a larger effect on DSO's incomes, compared with today.

From the perspective of customers, energy-based distribution tariff would prod people to use less energy. Electricity retail tariff would also strengthen that impact. Energy-based tariff does not include incentives to decrease the demand of electrical power. It can be discovered that tariff structure, which is energy-based only, wouldn't be the best solution, because it wouldn't have appropriate incentives and it wouldn't be cost-reflective either.

5.3 Dynamic tariff

Another option, which would prod people to optimize electricity usage from the distribution network point of view, would be a dynamic energy tariff. In this model, the price of the delivered energy (c/kWh) would change according to the time of day. Nowadays, almost the same model is used in 2-time tariffs, where energy price is lower at night time. This model includes only two time and price levels, though there could be more periods. After couple of years almost all customers will have smart meters. Then, fee of the distributed energy could be time-related and it could change more dynamically than today. In this model the price could be scaled so that when the load of network is the highest, the price would also be the highest and vice versa.

However, this kind of tariff structure has problems, from the customers and DSO's point of view. Electricity consumption varies a lot between different consumer types. Domestic consumers' peak powers are in the evenings, whereas workplaces use the main amount of electricity in the morning. Therefore, time structure for pricing should be e.g. substation specific. This could lead to different electricity prices in the DSO's network area and Finnish electricity market law prohibits that. Using different price levels would make the system complicated to understand for the customers. In addition, this kind of electricity distribution tariff structure could create contradictory incentives between electricity sale and distribution tariffs, if expensive and cheap distribution and market prices do not coincide. Market-based demand response and electricity distribution pricing would direct consumption contradicting ways.

This tariff structure would be too complicated and it would have contradictory incentives from customers' point of view. Also DSO's requirements for tariff structure are difficult to fulfill.

5.4 Power based tariff

In power based pricing distribution fee is based on peak power of the network during the certain time period or subscribed power capacity. Power-based pricing is commonly used by customers, who consume high amounts of electricity. Small-scale customers do not have this kind of tariff structure in Finland. For example in Sweden, Sollentuna Energi has requisitioned power based pricing for all customer types. Sollentuna Energi's network fees are based on the size of main fuse and peak powers during weekdays [13].

In practice, power tariff is cost-reflective from the DSO's point of view, because pricing method is same as the most essential cost factor. Distribution incomes are also easier to predict than in the energy based model. This is due to structural changes in electricity end-use, for instance air-to-air heat pump in electric heating house have typically smaller effect on power than energy.

Power-based alternative could be a power band pricing (PBP). The concept would mean that a customer would subscribe to the desired electricity distribution capacity. Billing is based on the subscribed capacity or metered peak power (kW). The customers' contracted power could be the transmission capacity that is the mean power of the highest hour e.g. 5 kW, 10 kW and 15 kW. It could also be based on the current (A), in such approach, also reactive power is included in the billing, but modifications for AMR meters and meter reading systems may be needed. In the case of the capacity subscription, certain procedure for exceeding the capacity limit (e.g. penalty fee)

is needed. This model can execute all the necessary requirements for distribution pricing and it seems a viable novel solution to distribution pricing. [9]

For a DSO, a benefit of power band pricing is the same power band and an almost constant turnover in different years. From the perspectives of customers, DSOs and the electricity market, PBP involves various positive features. The key benefit for DSO of power band pricing is cost-reflective tariff structure. Benefits for customers are incentives to decrease peak power (e.g. by optimal dimensioning of DER). Power-based pricing would encourage the customers to reduce their contracted power, and the loads could be balanced more evenly. In long run, it increases capacity utilization rate in distribution network, which decreases the costs of the electricity distribution. The power band pricing could make the customer's electricity bill more intelligible also. The average network fees of customers would not change and the revenues of the DSO would remain constant. Also the average proportion of the distribution network in the total price of electricity would remain same level. [9]

6 CONCLUSIONS

Improving of energy efficiency and reduction of the environmental effects of power generation require changes in the present distribution tariffs. DSOs' tariff structure should encourage the end-users to behave so that the energy efficiency of the whole energy system is maximised and the total costs are minimised. In addition, the pricing methodology has to be cost reflective, equitable and understandable.

Traditional distribution tariff structure in Finland is energy based tariff combined with a fixed fee, which is typically dependent on the size of the main fuse (cents/kWh + €/month). This kind of tariff structure is not very cost reflective and it does not include efficient incentives to optimize electricity usage. These are challenging factors in future, when operational environment is changing. Furthermore, the new technology, as smart metering, may provide new opportunities for tariff planning.

Energy efficiency actions have effects on the distributed energy and power demand. Finally, impacts can be seen in DSOs incomes and revenues. However, DER and DR effects on DSOs' revenue can be managed by tariff planning. In practice, DSOs costs are mostly dependent on power. At the moment a big part of incomes are based on the amount of delivered energy. Changes in electricity usage don't effect at the same way in the costs and incomes on the current tariffs. For instance, energy efficiency actions decrease DSOs revenue, but don't have an influence on costs. Customers don't have incentives to optimize electricity usage from the network point of view. Solution for avoiding negative impacts for DSO is to develop more cost reflective tariff structure.

Considering the alternative tariff structures, the study shows that best solution would be power based tariff structure, which is called power band pricing (PBP). In the power band scheme, a customer's distribution tariff depends on the subscribed power band. It is concluded that power based tariff is the best solution, because it is equitable, cost reflective for DSO and provide customers with incentives to optimize their power consumption.

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