EFFECTS OF DEMAND RESPONSE ON THE END-CUSTOMER DISTRIBUTION FEE

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ABSTRACT

Intelligent load control can save significant amount of investment money in distribution networks. This may also have a positive effect on the distribution fees paid by electricity end-users. Analyses on actual electricity distribution networks have shown that shifting of load during peak hours will decrease future reinforcement investment needs in networks. In the case scenario, the present distribution fees paid by electricity end-users could be decreased by 5–20 %. In the paper, the methodology to define the effects of load control on end-customer distribution fee is discussed.

INTRODUCTION

The research in the area of demand response (DR) has been intensified in recent years as a result of the annually growing consumption and shortage of generation capacity. Demand response will relieve the stress on the power grid on one side and temporarily eliminate the need to renovate the network and expand generation capacity on the other side. In the European countries demand response has been implemented mostly for large industrial and commercial customers, whereas for residential customers it is still underdeveloped [3]. Different types of houses, consumption habits, and lack of measurement data make it difficult to estimate the impact of load control of small customers on the distribution company business and remain a significant barrier against DR implementation.

It is worth emphasizing that demand response of residential customers will first of all be reflected on the electricity market players at the distribution level, that is, distribution system operators, retailers, and aggregators. This paper aims to estimate the effects of electric heating load control of residential customers on the distribution company. There is a high DR potential in electric heating in Finland, since the majority of electricity end-customers in rural areas live in houses heated with electricity; a load of this kind has a relatively high energy consumption compared with other domestic appliances, and it can be shifted without disturbing the comfort of the customer. The studies presented in the paper are based on actual measurements of electricity consumption and analyses of customer load curves and values of a distribution network.

It has been found out that the end-customer distribution fees can be cut, if the load is shifted by one or two hours from the evening peak hours. The other load control impact yields that the use of the present transformer and transmission capacity in electricity distribution systems can be extended by years. This provides an opportunity to postpone future reinforcement investments. Furthermore, local energy storage units were modelled and integrated into the experiment, and the impact on the load curve shape was investigated.

TARGET OF THE STUDIES AND BACKGROUND DATA

The main target of the paper is to describe the methodology of defining the effects of DR on distribution fees. This is done by analyzing opportunities to decrease present peak power by adjusting electric heating load of the end-customer. The principle of DR analyses is presented in Fig 1.

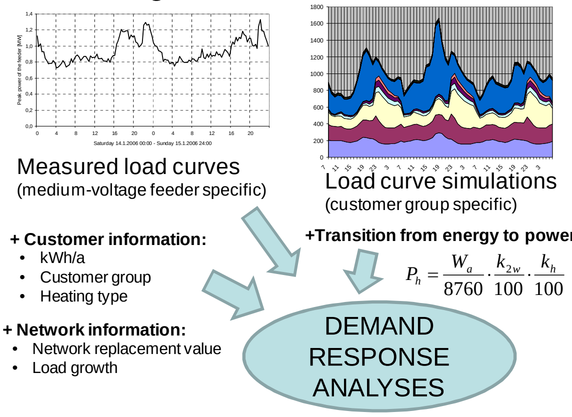

Fig. 1. Background data used in analyses.

The main idea is to combine information of actual feeder specific measured load and customer group specific load curve simulations together. When the annual energy consumption and type of customers of a feeder are known, hourly power demand can be estimated. Using two-week and hour indices k_{2w} and k_h, which are given for each customer group, the transformation from annual energy to mean hourly power is possible [1] (Fig. 1). A two-week index shows how much higher the two-week period mean power is compared with the yearly mean power. An hour index in turn shows how much higher the hourly mean power is compared with the mean power of the two-week period. Thus, the mean hourly powers can be calculated for each hour of the year for every customer group.

The obtained model load curve is drawn to quantify the contribution of each customer to the hourly power. Due to the lack of information, the simulated load curve does not take into account the probability and temperature variation; hence, the peak power of the feeder may not be realistic in all cases. For this purpose, it is useful that the measured load curve shows the real peak power of the feeder. After the peak power reduction potential is found, two kinds of benefits can be estimated for the company:

1. Temporary savings as a result of deferred reinforcement investments, which can be put in the network later.
2. Permanent savings obtained annually from peak power reduction and reflected in end-customer distribution fee cut.

Analyses of the DR potential of the case feeder and its impact on the distribution company are based on the above-described methodology (Fig. 1), using measurement data and load curve simulations.

Measurements play an important role when the opportunities and benefits of DR are estimated. Figure 2 presents the load curve of the case network (20 kV feeder). The majority of customers (96%, 438 in total) supplied by the feeder are residential customers, who live in detached houses with the type of heating shown in the figure. Most customers with electric heating loads use the 2-time tariff, which can be noticed in their hourly power rise at 22:00 when the night-time tariff starts. Customers with *direct electric heating* loads are equipped with water storage heaters. In this paper, it is assumed that each heater has a volume of 300 litres and a rated power of 3 kW. The households with storage electric heating are equipped with larger water and space storage heaters; their rated power may vary from 5 to 20 kW depending on the household size. The 1-hour and 2-hour shifting has been simulated for both types of customers with electric heating.

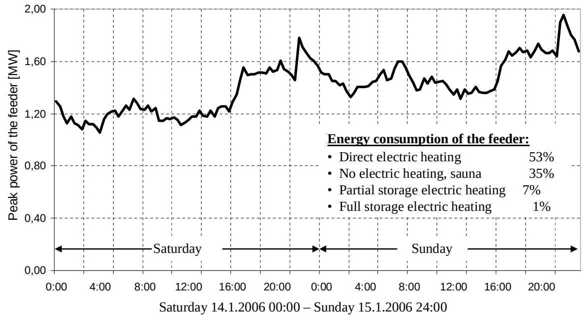

Fig. 2. Load curve of the case feeder.

In the actual network, feeders vary greatly by their number and types of customers, and consequently, by their peak power reduction potential, that is, demand response potential. For this reason, in order to define the change in distribution fees, and other DR benefits for the company, the whole network has to be taken into consideration.

DEMAND RESPONSE POTENTIAL

The focus of the studies is on the customers with direct, full, and partial storage electric heating, since they comprise the major flexible groups in terms of load control. According to the measured load curve, the hourly power increases by 250–300 kW every day of the week after 16:00 (sauna, cooking) and immediately after 22:00 (heating storages) as seen in Fig. 2. The study of the obtained hourly powers of each customer group shows the following contribution of customers with direct and storage electric heating to the peak power at 21:00 and 22:00 on a winter Saturday evening.

Table 1.Contribution of different customer groups to the peak power of the case feeder at 21:00 and 22:00 on a winter Saturday evening.

Type of electric heating of customers	**P, 21:00, kW**	**P, 22:00, kW**
Direct, floor heating > 2 kW, water storages 300 l	508 (33 %)	753 (42 %)
Direct, water storages < 300 l	288 (19 %)	269 (15 %)
Partial storage	107 (7 %)	183 (10 %)
Full storage	23 (1.5 %)	60 (3.3 %)
No electric heating, electric sauna	536 (35 %)	464 (26 %)
Total	**1520 (100 %)**	**1780 (100 %)**

Table 1 shows that the hourly power increases partly because of the partial, full storage, and direct electric heating loads. The peak reduction potential can be roughly estimated by subtracting the values of hourly powers of the hour 21:00 from the values of the hour 22:00. Taking into account that an increase in consumption also occurs owing to the evening household activities (cooking, lighting, computers, TV, etc.), we assume that about 220 kW of direct electric heating load and 100 kW of full and partial storage electric heating load can be controlled.

DEMAND RESPONSE SCENARIOS

The amount of peak power reduction depends on the number of customers simultaneously involved in DR actions. In the paper, the amount of shifted load varies from 20 % to 100 % of the value defined in the previous section (320 kW). When shifting the load, it is assumed that 100 % of the shifted energy is transferred to the hour when the load is recovered.

Two scenarios have been considered. In the first case the shifting operations start at 22:00 and stop at 23:00. The second case considers shifting from 22:00 to 00:00. The simulations have shown that the maximum power peak reduction is possible when 20 % is shifted by one hour or 60 to 100 % is shifted by two hours. However, the highest DR potential of the case feeder is limited to 180 kW (10.1 %) because of the peak power of 1.6 MW occurring at

20:00. The impact on the load curve is illustrated in Fig. 3.

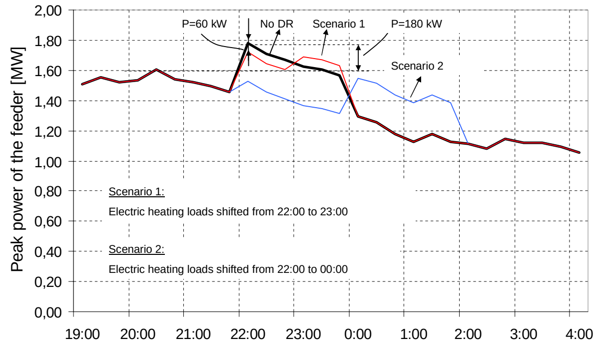

Fig. 3. Impact of load control on the load curve. 64 kW is shifted by one hour and 256 kW by two hours.

The results of the other load control scenarios are presented in Table 2.

Table 2. Power peak change in different load control scenarios.

Shifted load	Number of simultaneously controlled water storage heaters, 3 kW/unit	Number of households, storage heating 5–20 kW/house	Power peak change, %	
			Shifting 22–23	Shifting 22–00
100 %–320 kW	73	20 – 5	9	-9.5
80 % – 256 kW	58	16 – 4	5.6	-10.1
60 % – 192 kW	44	12 – 3	2.3	-10.1
40 % – 128 kW	29	8 – 2	-1.7	-7.2
20 % – 64 kW	14	4 – 1	-3.4	-3.6

The desired power peak reduction can best be achieved if a customer acts as an active participant of the network via an interactive customer gateway installed on the customer's premises. The principal assumption of the paper is that all residential customers of the case feeder are equipped with interactive customer gateway infrastructure, which includes AMR and enables two-way communication between the customer and the aggregator. The latter obtains information about each customer's hourly consumption and can thereby analyze his contribution to the peak power of the feeder. The task of the aggregator is to send requests to that number of customers whose total reduction potential will contribute to the power reduction of the peak hour interval (evening peak around 22:00).

LOCAL ENERGY STORAGE UNITS

Local energy storage units will play a multifunctional role in electricity distribution networks. In this case, we consider them as a means of load levelling. One of the questions of the paper is to quantify the contribution of local energy storages to the power peak reduction. For this purpose, an assumption about the penetration rate and energy content of storages has to be made. The principal assumption is that one detached house might own a 10–20 kWh energy storage unit, which is near to the capacity of an electric car battery. In calculations, 10 kWh units are considered in order not to overestimate the peak power reduction. The penetration rate varies from 5 to 30 %, which will give an energy content of 220 kWh to 1320 kWh, respectively. It has been simulated that charging lasts 8 hours from 8:00 to 16:00, and discharging – 7 hours, from 17:00 to 01:00, with one hour break when the load is being shifted for the 2nd scenario and continuously for the 1st scenario. Thus the maximum peak power reduction can be obtained. Figure 4 shows how energy storages affect the load curve, with and without load control. The peak reduction is higher in combination with load control, which proves that the value of energy storages is higher when demand response takes place.

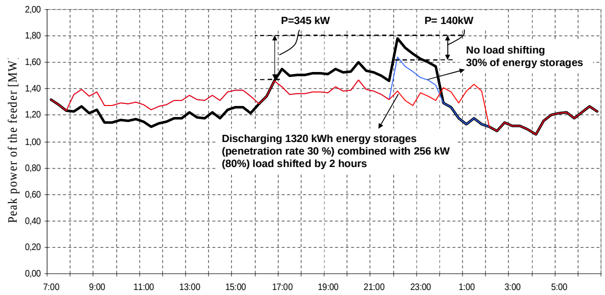

Fig. 4. Impact of energy storages on the load curve.

DEMAND RESPONSE EFFECTS ON A DISTRIBUTION COMPANY

Effects on distribution fees

The amount of required investments can be estimated by defining the average marginal cost of the network [2]. It is based on the network replacement value and the maximum load of the year, and it describes how much the network capacity has cost for the distribution company per each peak load kilowatt. In the example network, the network value compared with the peak load is 1000 €/kW, which includes the value of medium-voltage and low-voltage networks as well as the primary substation level. If the peak reduction of the network is for instance 176 kW, estimation of savings in the network investments are:

$$C_{\Sigma} = NV \text{ x } \Delta P = 1000 \text{ €/kW x } 176 \text{ kW} = 176 \text{ k€}. \qquad (1)$$

Considering a period of 10 a and an interest rate 5 %, the annual saving of 176 k€ is 22.8 k€/a. The cut in distribution fees is found as annual savings divided by the annual energy consumption resulting in 0.4 cent/kWh (=22.8 k€/5.7 GWh). The calculation results for the other scenarios are presented in Table 3.

Delay in reinforcement costs

In order to estimate for how long reinforcement investments can be delayed, the load growth rate (*r*, %) and the demand response potential (ΔP, kW) are required. The peak power in 10 years with the load control actions taken into account can be defined by Eq. 2.

$$P_{10} = \left(P_1 - \Delta P\right)\cdot\left(1+\frac{r}{100}\right)^t \tag{2}$$

where

- P_1 hourly mean power of the 1st year of the reference time period, kW
- P_{10} hourly mean power of the 10th year of the reference time period, kW
- ΔP demand response potential, kW
- r load growth rate, % (in this paper 1.5 %)
- t reference time period, a (in this paper 10 a)

After the peak power for the 10th year has been calculated, the delay in reinforcement investments can be defined as the difference between the reference period of 10 a and the number of years in which the peak power without load control actions will occur (Table 3).

Table 3. Effects of demand response on the case company.

	Scenario	Peak power reduction		Annual savings	Distribution fee cut	Delay in invest-ments
		%	kW	k€/a	cent/kWh	
No energy storages	I, 20%	3	60	7.7	0.14	2 a
	II, 80%	10	180	22.8	0.4	7 a
Energy storages, 5%	I, 20%	5	90	11.7	0.2	3.5 a
	II, 80%	11	208	26.9	0.47	8.4 a
Energy storages, 30%	I, 20%	13	250	32.4	0.57	10.1 a
	II, 80%	19	345	44.7	0.78	14.5 a

Value of local energy storages

Assuming the price of the energy storage units 7 k€/10 kWh, the annual investments for a 10-year period with the 5 % interest rate will vary from 20 to 120 k€ for the penetration rates 5–30 % respectively. This shows that the benefit for the scenario II with 5 % of energy storages is positive and equal to 6.9 k€/a. In the three rest scenarios the energy storages are not profitable since the annual savings from the peak power reduction are lower than the annual investments needed in the energy storages. Figure 5 illustrates how the number of energy storages in the network, when combined with load control, affects the peak power reduction of the feeder and the distribution company annual savings. It shows that the technical profitability is limited to 30 % penetration rate in this case. The higher number of energy storages will reduce the power peak only a little bit and the benefits will decrease because of the rising storage expenses. The 7 % penetration rate corresponds to the balance between annual savings and investments. Thus, this is the maximum number of storages which is beneficial at the present moment.

Cost benefit is strongly dependent on the price of energy storages and the load curve of the present feeder. It can be estimated that the prices of energy storages will decrease in the future.

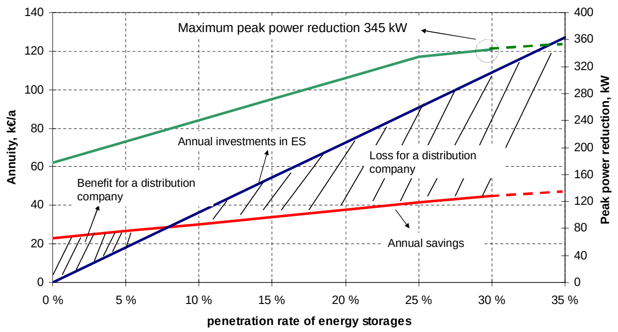

Figure 5. Cost benefit analysis of energy storages

If the unit price would be half compared to the case price (3.5 k€/a), the maximum beneficial penetration rate rises up to 20 % with 300 kW reduction potential. This demonstrates that the benefits for the network will be higher as the price of energy storages goes down.

CONCLUSIONS

There are remarkable incentives to control the peak load of electricity distribution networks by demand response. The methodology for defining the effects of demand response on the end-customer distribution fee has been described in this paper. The results are strongly dependent on the load curve of customers. In the future, when more customers are equipped with AMR, an analysis based on customer –specific measurement data and the presented methodology will yield more reliable results for a distribution company.

The further important research question is the impact of local energy storages on the performance of both customers and superior electricity market players (DSO, aggregator). While the information about energy content and penetration rate is needed to estimate the effect on the medium voltage networks, finding the optimal location and distribution of energy storages will demonstrate the challenges and benefits for the low voltage networks.

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