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 has been intensified in recent years due to 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 European countries demand response has been implemented mostly for large industrial and commercial customers, whereas for residential customers it is still underdeveloped. Their large amount, different types of houses, consumption habits, 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 towards demand response implementation.

It is worth to emphasize that demand response of residential customers will first of all be reflected on the electricity market players of the distribution level, i.e. distribution system operators, retailers, aggregators. This paper aims to estimate the effects of electric heating load control of residential customers on the distribution company.

There is a high demand response 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 for 1 or 2 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 demand response on distribution fees. This is done by analyzing possibilities to decrease present peak power by adjusting electric heating load of the end-customer. Principle of demand response analyses is presented in Fig 1.

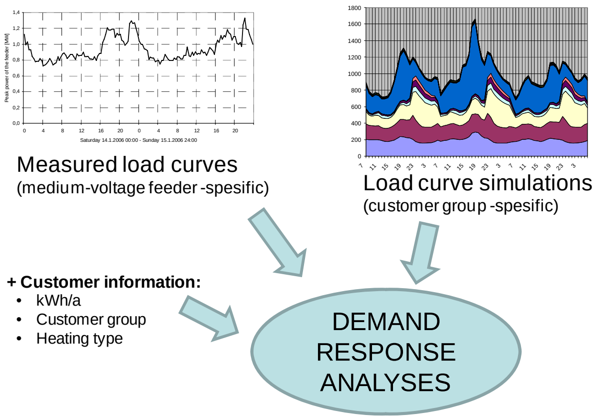

Fig. 1. Background data used in analyses.

The main idea of the Fig 1. is to combine information of actual feeder –specific measured load and customer group specific load curve simulations together. For each feeder it is necessary to define different customer groups and determine the amount of load that can be shifted by aggregator.

When information about the annual energy consumption and type of customers of a feeder is available, hourly power demand can be estimated. Using so called two-week k_{2w} and hour-indexes k_h which are given for each customer group, the transformation from annual energy to the mean hourly power is possible, using the Eq. 1. A two-week index shows how much the two-week period mean power is higher than the yearly mean power. An hour index shows how much the hourly mean power is higher than 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 [1].

$$P_h = \frac{W_a}{8760} \cdot \frac{k_{2w}}{100} \cdot \frac{k_h}{100} \quad (1)$$

The obtained model load curve is drawn to quantify the contribution of each customer to the hourly power. The simulated load curve does not take into account probability and temperature variation due to lack of information; hence the peak power of the feeder might not be realistic in all cases. For this purpose the measured load curve is useful to show the real peak power of the feeder.

After peak power reduction potential of each feeder is found, two kinds of benefits can be estimated for the distribution company:

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

Analyses of demand response 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 have important role when possibilities and benefits of demand response are estimated. In Fig. 2 load curve of case network (20 kV medium-voltage feeder) is presented. The peak power of the feeder is 1.78 MW on a winter Saturday evening. The customers supplied by the case feeder represent 96 % of residential customers (438 customers) who live in detached houses with the type of heating shown in the figure.

Electrically heated customers use 2-time tariff which can be clearly 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 an average volume of 300 litres and rated power of 3 kW. The households with storage electric heating are equipped with

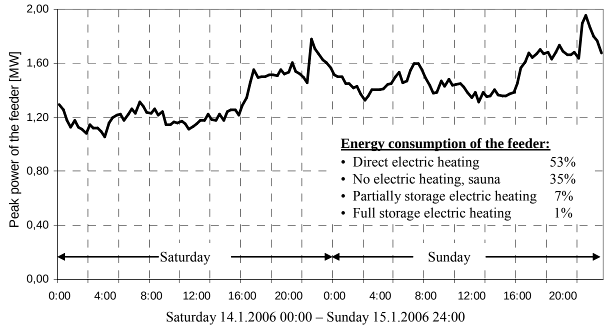

Fig. 2. Load curve of the case feeder.

larger water and space storage heaters; their rated power may vary from 5 to 20 kW depending on the household size. For both types of electrically heated customers 1-hour and 2- hour long shifting has been simulated.

In the actual network, feeders vary greatly on amount and types of customers, and therefore, different peak power reduction potential, i.e. demand response potential. For this reason, in order to define the change in distribution fees, and other demand response benefits for the company, the whole distribution network has to be taken into consideration.

DEMAND RESPONSE POTENTIAL

The focus of the studies is directed 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 in 250–300 kW every day of the week after 16:00 (sauna, cooking) and immediately after 22:00 (heating storages) as seen in Fig. 1. The study of the obtained hourly powers of each customer group has shown the following contribution of customers with direct and storage electric heating to the peak power at 21 and 22 on a winter Saturday evening.

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

Type of electric heating of customers	**P, 21:00**	**P, 22:00**
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 %)**

From the Table 1 it can be noticed that hourly power increases partly due to partial, full storage and direct electric heating loads. The power 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 increase in consumption also occurs due 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 partially 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 demand response actions. In the paper the amount of shifted load varies from 20 % to 100% of the value, defined in the previous chapter. When shifting the load, it is assumed that 100 % of the shifted energy is transferred to the hour when the load is recovered.

In this paper two scenarios have been considered. In the first case 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 for 1 hour and 80 % is shifted for 2 hours. The impact on the load curve shape is presented in Fig. 3.

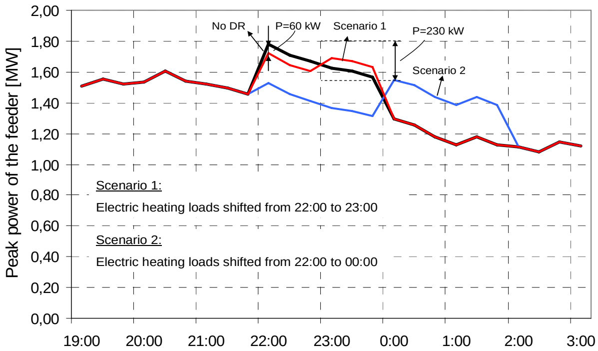

Fig. 3. Impact of load control on the load curve shape. 60 kW are shifted for 1 hour and 256 kW are shifted for 2 hours.

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
80 % - 256 kW	58	16 - 4	6	-13
60 % - 192 kW	44	12 - 3	2	-11
40 % - 128 kW	29	8 - 2	-2	-7
20 % - 64 kW	14	4 - 1	-3	-3

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 an aggregator. The latter obtains information about each customer's hourly consumption and therefore can analyze his contribution to the peak power of the feeder. The task of aggregator is to send requests to that amount 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. If charged during the night time using cheap electricity, they can be used during evening peak power hours and thus alleviate the stress on distribution networks.

One of the questions of the paper is to quantify the contribution of local energy storages to the power peak reduction. For this purpose assumption about penetration rate and energy content of storages has to be made. For the storages two limit cases are investigated in the paper:

1. Low penetration rate of energy storages, i.e. 5 %.
2. High penetration rate of energy storages, i.e. 50 %.

The principal assumption is that one detached house might own a 10–20 kWh energy storage unit, which is equivalent to the capacity of an electric car battery [2]. In calculations 10 kWh units are considered in order not to overestimate peak power reduction.

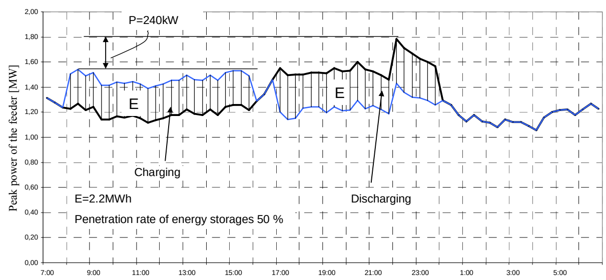

Fig. 4. Impact of energy storages on the load curve shape.

There are 438 residential customers; hence 5 % and 50 % of households with energy storages will give energy content of 220 kWh and 2200 kWh respectively. The impact of local energy storage units on the load curve shape is presented in Fig. 4, provided that charging takes place during the day, and discharging occurs during the evening peak hours.

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 primary substation level. If peak reduction of the network is for instance 60 kW, savings in the network investments are:

$$C_{\Sigma} = NV \times \Delta P = 1000 \text{ €/kW} \times 60 \text{ kW} = 60 \text{ k€}. \qquad (2)$$

Considering the period of 10 a and interest rate 5 %, annual saving of 60 k€ is 7.7 k€/a. This is obtained for the 1st scenario with 20 % of shifted energy. If total distributed energy of the case feeder is 5.7 GWh/a, the cut in distribution fees is found as annual savings divided by the annual energy consumption resulting in

$$7.7 \text{ k€}/5.7 \text{ GWh} = 0.14 \text{ cent/kWh}. \qquad (3)$$

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, load growth rate (r, %) and demand response potential (ΔP, kW) are required. The peak power in 10 years with load control actions taken into account can be defined using the Eq. 4.

$$P_{10} = (P_1 - \Delta P) \cdot (1 + \frac{r}{100})^t \qquad (4)$$

where

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

After the peak power for the 10th year is calculated, the delay in reinforcement investments can be defined as the difference between the considered period of 10 a and the number of years in which the peak power without load control actions will occur. Calculation results are presented in Table 3.

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

	Scenario	Peak power reduction %	Peak power reduction kW	Annual savings k€/a	Distribution fee cut cent/kWh	Delay in investments
No energy storages	I, 20%	3	60	7.7	0.14	2 a
	II, 80%	13	230	29.7	0.5	9 a
Energy storages, 5%	I, 20%	5	90	11.7	0.2	3.5 a
	II, 80%	16	260	33.7	0.6	10.6 a
Energy storages, 50%	I, 20%	13	240	31	0.55	9.7 a
	II, 80%	13	240	31	0.55	9.7 a

Value of local energy storages

If the price of energy storage units is assumed to be 7 k€/10 kWh, the total investments will be varying from 140 k€ to 1400 k€ on the case feeder depending on the penetration rate. The annual investments are 18 k€/a and 181 k€/a for a 10 year period with 5 % of interest rate. This shows that the benefit for the scenario II with 5 % of energy storages is positive and equal to 7 k€/a. In scenario I the energy storages are not profitable since annual savings from peak power reduction are lower than annual investments needed in energy storages. In case of 50 % penetration rate, the investments are six times higher than annual savings.

CONCLUSIONS

The methodology for defining the effects of demand response on a distribution company has been described. The results are strongly dependent on load curve shape of customers. In future, when more customers are equipped with AMR, analysis based on measurement data for all feeders and the presented methodology will yield trustworthy results for a distribution company.

The further important research question is the impact of local energy storages on performance of both customers and superior electricity market players (DSO, aggregator). Information about penetration level, energy density and cost of energy storages is required to carry out a cost/benefit analysis of local energy storage units.

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