POWER-BASED DISTRIBUTION TARIFFS FOR RESIDENTIAL CUSTOMERS – A RISK FOR OVERLOADING OF NETWORK IN AREAS WITH HIGH PENETRATION OF TIME-OF-USE DSO TARIFFS?

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ABSTRACT

Finnish distribution system operators (DSO) have had to provide customers distribution tariffs with different prices on different time of uses (TOU). When electricity system is developing from centralized production and consumption customers to decentralized prosumer customers and multidirectional power flows, traditional tariff systems do not incentivize to overall efficient use of capacity and resources.

This paper focuses on studying effects of present nighttime tariff customers' load control actions on distribution grid loads. The network analysis is performed on secondary transformer level with real hourly customer load demand data.

INTRODUCTION

In Finland, DSOs have offered TOU tariffs such as nighttime tariff and seasonal tariffs for residential customers for decades. The proportion of DSOs' TOU customers is typically between 10–20%. Originally, the nighttime tariff or the seasonal tariffs have been set to guide customers to adjust flexible controllable load resources such as heating loads with water storage to off-peak hours. On the other hand, common price signal has caused an effect that all customers' controlled loads turn on at the first inexpensive hour, which can cumulate locally peak powers in low-voltage network and distribution transformers.

Background of the study

Distribution system operators' tariffs have been energy-based fees, but proportion of fixed fees has been increasing. Amount of transferred energy does not correlate well with DSO's cost structure. Changes in the energy system, for example distributed generation and electrification of transportation cause more variability in grid power, especially in the customer end. In the changing environment DSOs' traditional tariffs do not direct customers' electricity demand towards efficient capacity use. Nighttime tariffs have been set to steer controllable loads from on-peak hours to nighttime hours, when system loads have been typically lower. With distributed production, in most cases solar PV production, there can be overproduction at daytime and load control actions towards nighttime are not that reasonable anymore.

TOU DSO tariffs

Traditionally DSOs have offered customers a possibility to choose distribution tariff that has lower cost for energy consumed at nighttime hours from 22:00 to 07:00. These tariffs have had higher price either for daytime consumption or fixed monthly payment, to direct only customers with significant controllable loads to these tariffs. For example a Finnish DSO has general tariff with consumption fee 0.0425 €/kWh and nighttime tariff with daytime consumption fee 0.0539 €/kWh and nighttime fee 0.0238 €/kWh. All prices include VAT 24%. The fixed monthly fee is the same in both tariff options. [1]

Ministry of Economic Affairs and Employment of Finland has established a working group that published their final report in October 2018. The working group proposes in their final report that load control that has previously been done by DSOs should be market based in the future and DSOs should not be forced to offer TOU tariffs anymore. The working group also states that power-based tariffs would also be good option instead of increasing proportion of fixed fees. [2]

Power-based tariffs

Power-based distribution tariffs (PBT) have been studied recently as an alternative to traditional DSO pricing. DSOs' costs are mainly fixed costs because of significant investments in grid infrastructure. [3-5]

Customer side loads are becoming more and more volatile because of micro-generation, electric vehicle charging and other appliances with high power consumption, such as battery energy storage systems. Traditional energy-based distribution tariffs have taken into account only total consumption over longer time period but do not take into account physical limitations from grid infrastructure. Power-based tariffs also give customers an incentive to limit peak powers. Even this kind of tariff structure still does not directly take into account bottlenecks in the distribution grid, but it encourages customers for better capacity efficiency.

Controllable loads

Controllable loads can include many different loads, which can be elastic to price signals. In Finland, typical load that has been controlled is electrical heating with storage boiler. Controllable loads have been set to turn on after 22:00.

METHODOLOGY

The study was made by defining customers that have flexible load controlled to nighttime by clustering. Controllable load was shifted with different assumptions to find out would it have an effect especially on distribution transformers load, if traditional load control is replaced with different scenarios. Power-based tariffs were taken into account as a limiting factor to customer load control.

Customer clustering

Hourly load data of 10808 customers were clustered using K-means clustering. This study uses the outcome of the clustering for targeting the load change for customers with loads turning on at nighttime. The customers that were identified as nighttime electricity users, whose consumption peaks after 21:00–22:00, depending on case area's DSO's tariff systems, consumption behaviour was altered.

Load control

Nighttime peak load was shifted with different assumptions in different scenarios. In reality, there might be practical challenges in implementation of these scenarios, for example hot water might be needed at certain time of day.

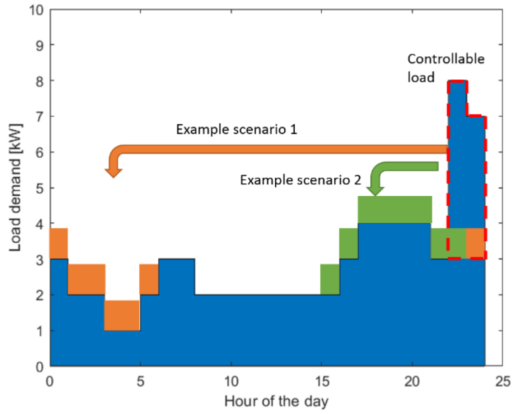

Figure 1. Basic example of controllable nighttime load and load control. Example scenario 1 means that evening controlled load is distributed to that night more evenly, not to previous morning.

Load control scenario A

In the first scenario, nighttime load is reduced and the consumption is shifted a few hours earlier, when other customers' peak loads and higher level peak load in most cases occur. This scenario is similar to Figure 1 example scenario 2.

Load control scenario B

In the scenario B, the nighttime load is distributed evenly through the day.

Load control scenario C

In the third scenario, nighttime load peak is flattened more evenly to that night. This scenario is similar to Figure 1 example scenario 1.

Power-based tariffs

Power-based tariff was assumed here to affect only so that customers, whose peak load would increase with assumed load control actions, would not change their consumption behaviour. Power-based tariff was expected to be charged based on customer's annual peak load. Figure 2 demonstrates annual power-based tariff with one customer's load curve.

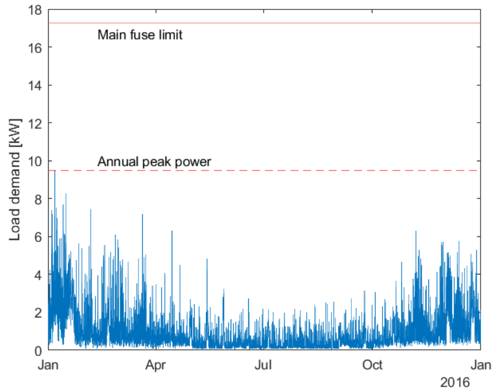

Figure 2. Example of annual power-based tariff.

With traditional tariffs the example customer would have payed for the total electricity consumption, 7.8 MWh, but with PBT payment would be for the peak power, 9.47 kW. Analyses in this study are done on hourly basis, because customers' load data is hourly load demand data from AMR meters.

RESULTS

The case study was performed on case area where proportion of identified nighttime load control customers was high. This case area includes 2799 customers in total. One quarter of these customers was estimated to have controllable load.

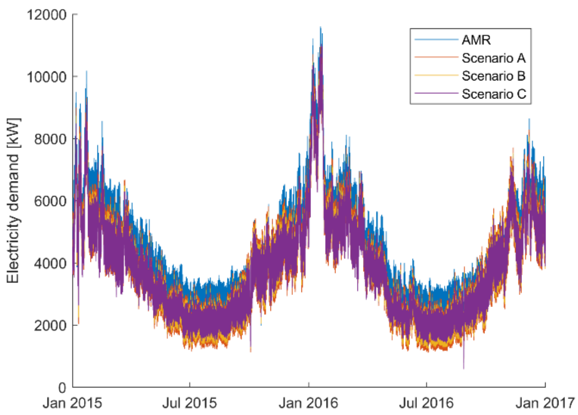

Figure 3. Case area load curve between years 2015–2017 including 2799 customers.

It can be seen from Figure 3 that electricity consumption can be about 3–4 times higher on wintertime than in the summer. Hourly load demand during peak load is illustrated in Figure 4.

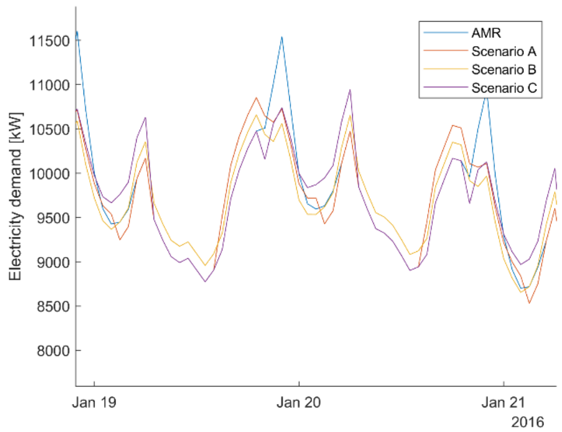

Figure 4. Case area load curve during wintertime peak load with different load control scenarios.

Figure 4 demonstrates the hourly load curve on primary substation level. It is visible that currently peak load occurs at nighttime, when TOU tariff lower price occurs after 22:00. If all customers that are identified as nighttime electricity consumers are expected to control their nighttime load differently, even the primary substation level peak load might decrease significantly.

Without PBT

First, study without considering customers' peak load limitations was done. Figure 5 illustrates customers' peak loads before and after load control scenario A.

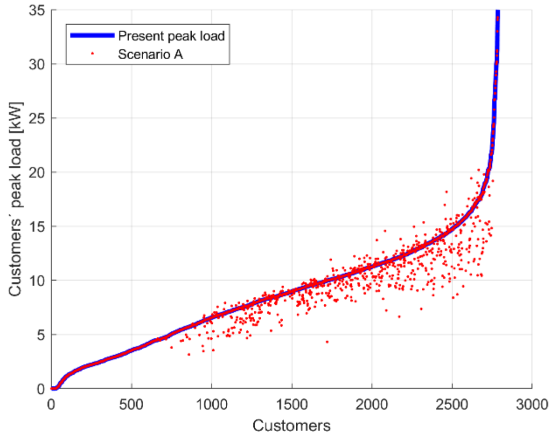

Figure 5. Customers' original peak load and peak load with load control scenario A.

All customers, which load was controlled in this study, had peak power between 5 kW and 20 kW.

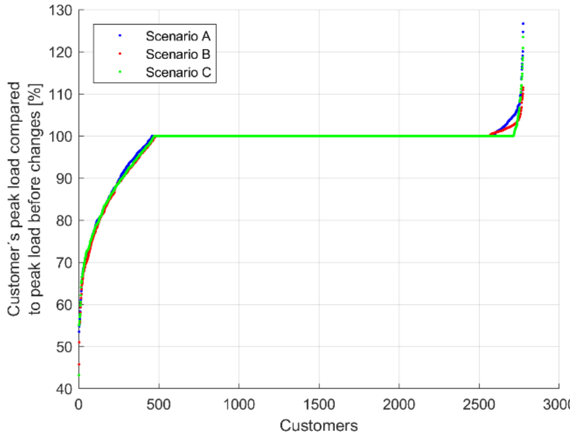

Figure 6. Relative change in customers' peak load with different load control scenarios.

It can be seen from Figures 5 and 6 that customers' peak loads can in some cases even halve by shifting the nighttime load. There are 470 customers, whose peak load decreases by shifting load from nighttime peak. On the other hand, there are also about 100 customers, whose peak power would increase. This happens because these customers have relatively high consumption also at different times than nighttime. For example, these loads might be caused by heating electric sauna in the evening. For these customers controlling nighttime load from PBT perspective is not reasonable if other loads are not controlled as well. These customers were kept in the study in the first step, but their control actions were also removed, because in case of PBT these control actions would be unprofitable for the customer.

Figure 7 illustrates secondary transformers' present load rates and peak load rates after load control actions.

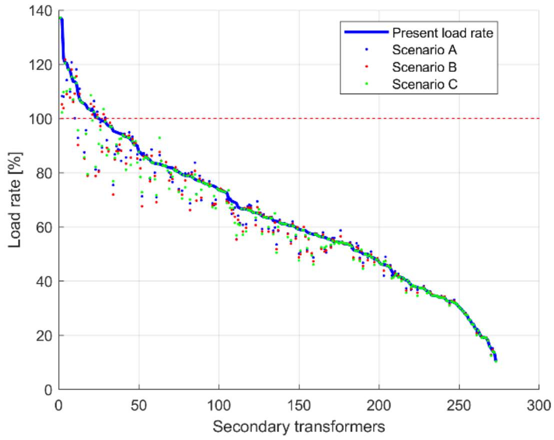

Figure 7. Secondary transformers' load rate change with different load control scenarios.

It is noticeable from Figure 7 that secondary transformers' peak loads are in most cases slightly decreased. Peak load in some transformers is also increased. Some secondary transformers have been on overload already. This is not serious problem if nominal power is exceeded on wintertime cold weather when transformer is naturally better cooled. Relative changes in secondary transformers' peak loads are demonstrated in Figure 8.

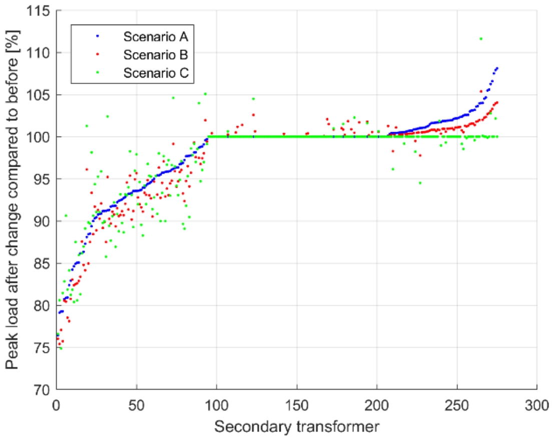

Figure 8. Change in secondary transformers' peak load without customer side peak load limitation

In Figure 8 transformers are sorted to scenario A's order. It is visible that different load control scenarios can have different outcomes on transformer loads. For example, there are transformers which peak load is decreased with the load control scenarios A and B, but with the scenario C the peak load is increased. In almost 100 secondary transformers the peak load is reduced. At the same time, there are about 50 transformers where peak load is increased. On the other hand, by studying Figure 7 it can seen that there are transformers that are already operating close to their nominal rate and which load might be increased by executing load control actions.

Average secondary transformer peak load decreases 4.1% in the load control scenario A. In the load control scenarios B and C the decrease in average peak loads are 5.0% and 4.6% respectively.

With PBT

In the case, when it is assumed that customers do not commit load control actions if their peak loads would increase, customers' peak loads are illustrated in Figures 9 and 10.

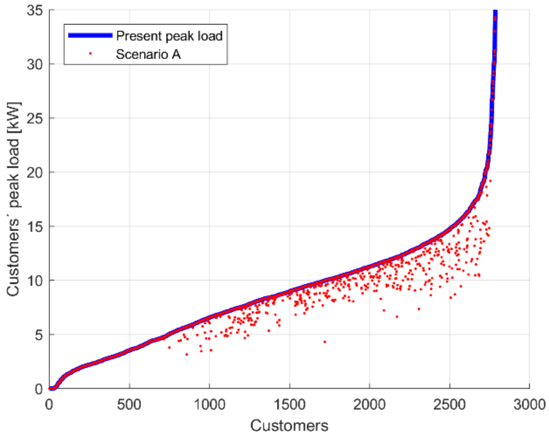

Figure 9. Customers' peak load before and after load control scenario A in case of PBT.

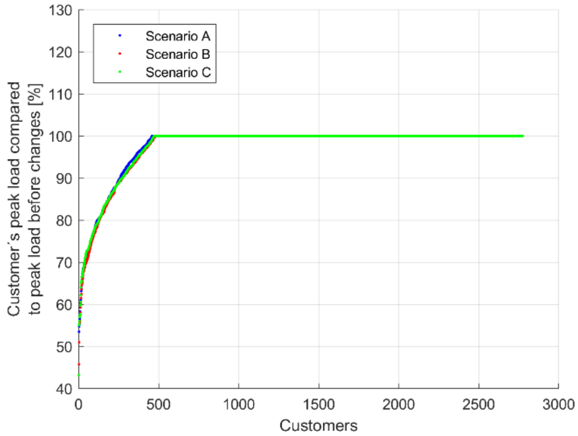

Figure 10. Relative change in customers' peak load with different load control scenarios in case of PBT.

It is visible in Figures 9 and 10 that customers' peak powers do not increase due to load control actions. Figures 11 and 12 demonstrate changes in secondary transformers' loads.

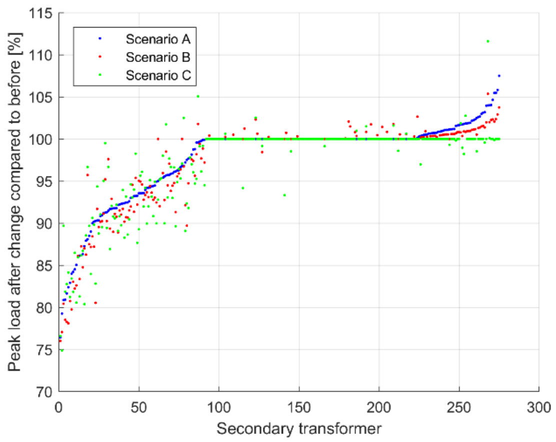

Figure 11. Relative change in secondary transformers' peak load with different load control scenarios and PBT.

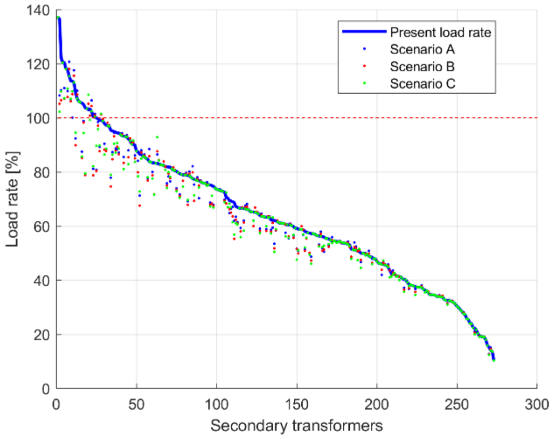

Figure 12. Secondary transformers' load rate with different load control scenarios and PBT.

By comparing Figure 7 to Figure 12 and Figure 8 to Figure 11 it can be seen that there are still transformers which peak load will increase, but there are less transformers which load rate is already high and where the load control actions increase the transformer's load.

With the PBT assumption average peak load decreased in the load control scenario A was 3.9%, and respectively in scenarios B and C, 4.7%. Thus, limiting load control actions to only those customers, whose peak power does not increase, reduced slightly the decrease of load rates in secondary transformer level. This happens because without customer-side peak load limitation there are more customers that control their load. In other words, customer's peak load does not always correlate well with grid peak load.

DISCUSSION

Customers', who were recognized to have flexible load that has been controlled to turn on after 22:00, flexible load was simulated to be controlled with different assumptions to different times of the day. Effects of load control on secondary transformers' peak load were studied. In this study it was assumed that customers, who do not have controllable loads which are set to turn on after 22:00, do not change their consumption patterns. In reality, power-based tariff might affect also other customers as well. Also the customers, that were limited out from the load control actions in case of PBT, would most likely also do something for other peak consumptions if possible. In a way, it seems that TOU tariffs have caused locally peak powers to rise on primary substation level and on secondary transformers. Same tariffs have to be available for all same kind of customers of a DSO, so this can lead to increasing local peak powers unnecessarily which can cause overdimensioning the grid.

CONCLUSIONS

The study shows that ending DSO driven load control that turns all controllable loads on at same hour of the day, would not cause problems to secondary transformers. In fact, in areas with high penetration of DSO's TOU tariffs, the controlled nighttime load might be actually causing the peak demand. In the studied case area customers that were causing the peak consumption to nighttime had increased their total load after 22:00 with 1 MW. With all load control scenarios the average peak load of secondary transformers decreased 4–5%. Limiting load control to customers, whose peak load would decrease by assumed load control, slightly reduced the effects on secondary transformers peak load.

In the future, it should be studied that would it cause problems to grid infrastructure if load control would be made driven by different market signals. In this study, estimated flexible loads were controlled more evenly to multiple hours, but if load control would be market-based, loads might be still controlled to turn on almost simultaneously. Power-based DSO tariff still most likely would affect so that a customer does not turn all the controllable loads on at once.

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