Effects of demand response on load profiling of small-scale customers

Kaisa Grip, Antti Mutanen, Pertti Järventausta
Tampere University of Technology (TUT), Finland

SUMMARY

It has been a tradition already for over some decades in Finland to use hourly load profiles for modelling customer behaviour e.g. in distribution network calculations. Now the large scale AMR roll-out in Finland has meant that almost every customer has a new AMR meter with features for hourly energy measurement as well as registrations of quality of supply and load control functionality. The AMR system offers a large amount of measurement data to determine more detailed load profiles, even customer-specific, and to improve modelling of temperature correlation of electrical loads.

However, electrical loads and customer behaviour are changing e.g. due to the customer's own small-scale production (e.g. PV systems), demand response, charging of electrical vehicles and energy storage possibilities. This sets new challenges for load profiling based on AMR measurements.

This paper discusses and examines the effects of demand response on AMR based load profiling of small-scale customers using measurements of a pilot customer over three years. The studied customer has a pilot of advanced HEMS (i.e. Home Energy Management System) having two different load controlling methods for demand response. One alternative to control loads is a power band based application which defines a power limit for electric loads. If the total loading read from the AMR meter exceeds the threshold value, the algorithm activates controllable loads (e.g. electric space heaters) to be switched OFF. Loads are returned ON when the total consumption goes under hysteresis value. As other application, the water boiler of the pilot customer is controlled by the spot-price of electricity. In this paper, previous years (i.e. 2010-2012) without demand response functionality are compared to year 2013 with HEMS based demand response applications.

KEYWORDS

AMR, demand response, load profiling, power band

1. INTRODUCTION

Smart Grids enable integration of large-scale distributed energy resources and demand response. Essential part of Smart Grids concept is AMR-meters which measure customers' energy consumption in real time. The large scale AMR roll-out in Finland has meant that almost every customer has a new AMR meter with features for hourly energy measurement as well as registrations of quality of supply and load control functionality.

Using the data of AMR-meters more accurate load models, even customer-specific, can be created, and modelling of temperature correlation of electrical loads can be improved [1], [2]. It has been a tradition already for over some decades in Finland to use hourly load profiles for modelling customer behaviour e.g. in distribution network calculations. Changes in electrical loads and customer behaviour (e.g. due to the customer's own small-scale production (e.g. PV systems), demand response, charging of electrical vehicles and energy storage possibilities) set new challenges for load profiling based on AMR measurements. As new loads, statistical charging load modelling of PHEVs in electricity distribution networks has been studied in [3]. This paper discusses first briefly on possible different load alternatives and their effects to the need of load modelling development.

Energy efficiency, small-scale energy production, energy storages and distributed generation will reduce the amount of transferred energy. However, these changes do not reduce the peak power considerably. Consequently, the revenue of the distribution system operators (DSOs) will decrease if the tariff structure does not change because in current tariff structure energy-based fee still forms the majority of the DSO's revenue. These changes in the operational environment drive the development of tariff structure, because the present tariffs are not capable of keeping the required income level. The development of metering devices and load control possibilities will support and bring new possibilities to the new tariff structures. The future network tariff structure should enable the demand response (DR) in a way that also the DSO would benefit from it. Power band tariff is considered one of the options for the future network tariff. The goal of the power band is to decrease the peak power level. That would relieve the stress on the distribution network and also temporarily postpone the need for network renovation. [4]

Home energy management system (HEMS) could help customers to achieve lower peak powers. HEMS is a system that enables the user to control and optimize the electricity consumption in a cost-effective way. HEMS includes additional home automation that enables monitoring and controlling of device-specific electricity consumption.

The purpose of load controlling and demand response is to move peak powers to the time period when the load is lower or the price of energy is cheaper. As a result customers' total electricity consumption is flattened but consumed energy stays almost the same than without load controlling. Effects of demand response can be examined with load curves and load duration curves.

The focus of this paper is on power band based load controlling and its effects to the pilot customer's loads. The studied customer has a pilot of advanced HEMS having two different load controlling methods for demand response (i.e power band based control and spot-price based control). In the study, HEMS was piloted in co-operation with a service provider company There Corporation Oy and distribution network company Elenia Oy. In the paper, previous years without demand response (2010-2012) are compared to the year 2013 with HEMS based demand response functionality.

2. ASPECTS ON LOAD MODELING

Present load models have been formed from AMR –measurements with an assumption that every customer has only normal energy consumption. In most cases this is valid at present. But there are also customers, who have e.g. own production beside the consumption. This kind of customers will increase in the future. This sets new challenges for load modelling.

When we consider AMR –measurements, we could differ four different cases, as illustrated in the Figure 1. AMR-data could consist of only load or production. The third alternative is combination of load and production and in the fourth case there is also energy storage. In addition to these there can be demand response functionality with all of above cases.

When a customer has only traditional consumption, load models are quite easy to create based on AMR data, if e.g. external temperature is also taken into account. In the future present load models will not be accurate enough because consuming habits and new functionalities (e.g. electrical vehicles) will change loads. Thus new methods for load modelling are needed.

AMR meter can measure also only production instead of the consumption. When the penetration of distributed generation (DG) will increase, the need to measure this production increases due to controlling and modelling purposes. Especially in case of renewable energy, there are many factors which affect to constitution of models. Both, solar and wind energy are dependent of weather and that makes modelling complicated.

Loads can be controlled by demand response functionality based on e.g. power limit or energy price. Modelling of combination of load and demand response is a challenging task, and it is needed to know e.g. when loads have switched on and off. Variation of energy price can be used to estimate demand response in a case when load is controlled by energy price.

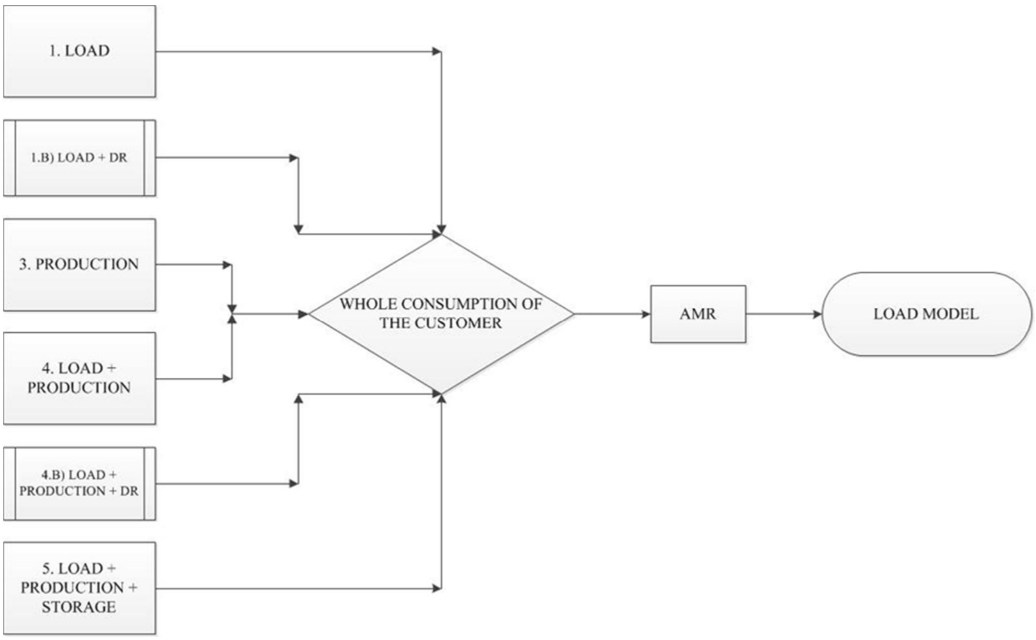

Fig. 1. Potential alternatives of combinations for AMR measurement

3. EXPERIENCES OF A PILOT CASE

This chapter presents experiences achieved by a pilot small-scale customer who has power band based load controlling system with four controllable heating loads. This pilot customer has also spot-price controlled hot water boiler.

3.1 Main principles of the pilot HEMS system

The concept of the pilot HEMS solution is illustrated in the Figure 2. The steering algorithm was developed by There Corporation Oy to support the power band tariff. The goal was to investigate whether the HEMS combined with the steering algorithm is able to allow smaller band sizes for the customers. The steering algorithm is based on the controllable loads that can be controlled to switch OFF when the total power consumption of the household increases. The bigger the number of the controllable loads the better. Loads that cannot be controlled are not able to include into the algorithm. So called power controller monitors the power consumption on a one minute time scale. It measures the average power of each minute. A certain power limit (kW), threshold value, is determined. When this power limit is reached, the algorithm starts to activate the controllable loads. The loads are arranged to a priority list according to the customer's wishes. The priority list determines in which order the loads are activated. If the threshold value is reached and all the controllable loads are already activated, an SMS message or e-mail is sent to the customer to inform that the power level is high. The message is sent only when there are not any controllable loads left to be switched OFF, so in order to reduce the power customer must do other actions. Hysteresis value was used to prevent the unwanted rapid switching of the load. After load is switched OFF the system waits until the total power goes under the hysteresis value before it switch ON any loads again. [4]

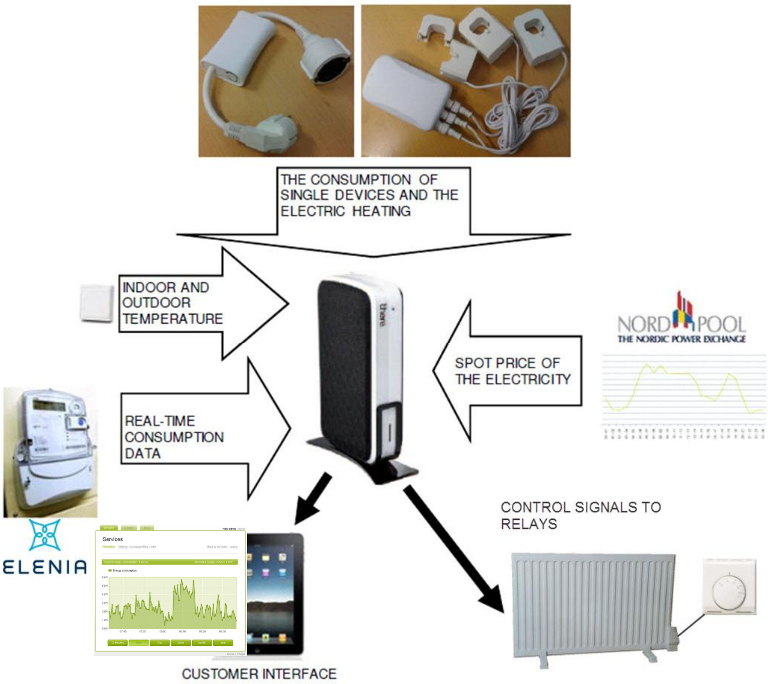

Fig. 2. The basic concept of the pilot HEMS solution [Emmi #]

With the pilot customer there were electric radiators with temperature drop functionality in master bedroom, kitchen, shower room and other three bedrooms, and all these were included into the steering algorithm. In addition, steering relay was added to the hot water boiler so it could be steered based on spot-price. Annual electricity consumption of the customer was 19,9 MWh. The customer was burning wood in the fireplace often and did not have electric sauna stove which help to keep the power level quite low. [4]

Figure 3 demonstrates behaviour of power band based controlling which is based on threshold and hysteresis value. Threshold value defines width of power band. In this case it was 6 kW. Hysteresis value in turn determines how much consumption needs to decrease so that controllable loads are switched ON again. For example when hysteresis value is 1 kW, as in this case, and threshold value is 6 kW, controllable loads are switched ON when the consumption measured by AMR meter is less than 5 kW. In the Figure 3 at time 12.37, the total power has been over 6 kW, so the first load (i.e. load number 1) has switched OFF. Power has gone under hysteresis value at 12.56 and load 4 has switched ON at 12.58. The final load has switched ON at 13.11.

3.2 Effects of load control to load curves

Power band and spot-price based controlling was introduced in the end of November 2012. Effects of controlling were studied over winter months, from the beginning of December 2012 to the end of February 2013, and the results were compared with previous years' corresponding months. During the study period the threshold value of the customer was varied to find a right value. Most of time value was at 6-7 kW level and hysteresis value was 1 kW for the whole period. In real commercial operation of power band both values should be constant.

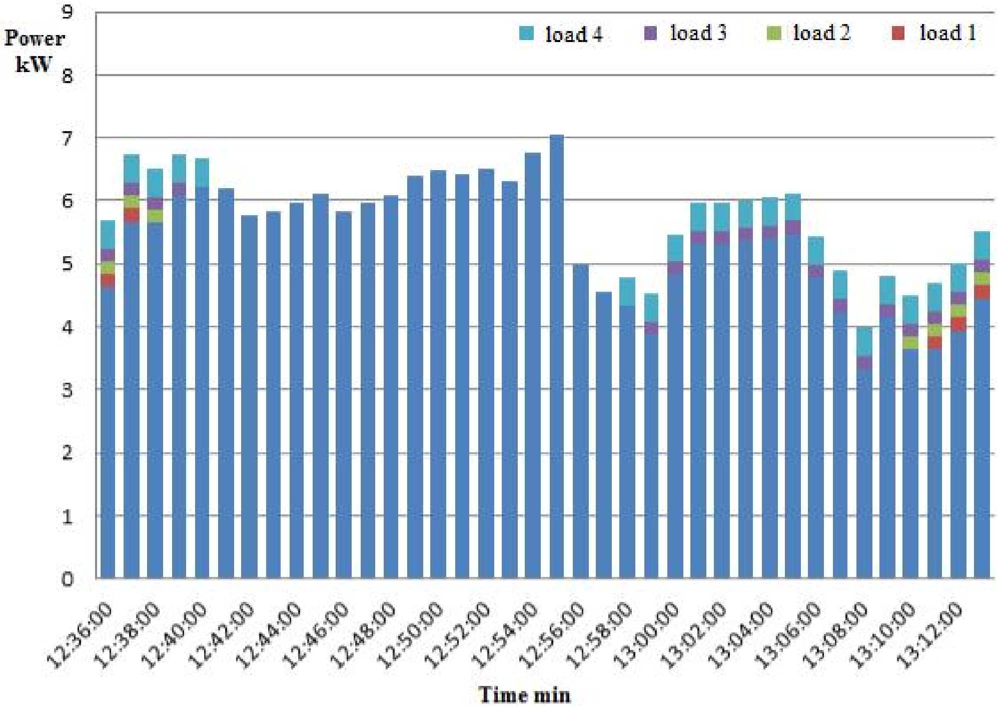

Fig. 3. An example on power band based load control

For more accurate study load curves of the pilot customer were created based on the previous years' hourly load data measured by AMR. In these curves temperature dependency of loads was taken into account. Figure 4 shows behaviour of loads in January of four different years (i.e. 2010-2013). Loads are shown as different day types. The first 24 hours represent typical weekday, next 24 h typical Saturday and rest 24 h typical Sunday. Green curve presents the controlled year 2013.

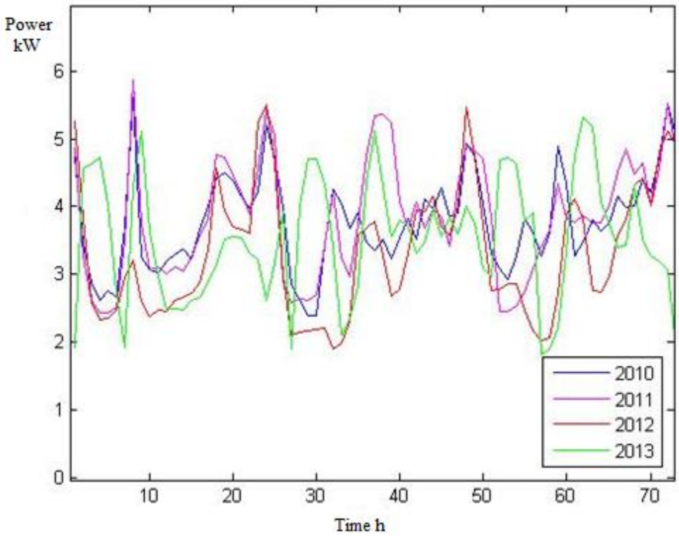

Fig. 4. Behaviour of loads in January of years 2010–2013

As it can be noticed from Figure 4 variation of loads is quite big between uncontrollable years. This variation can be explained by normal dispersion. Figure 5 presents two load curves: blue one presents the joined curve based on years 2010-2012 and the red one the controlled year 2013. Figure 5 has the same time period than Figure 4.

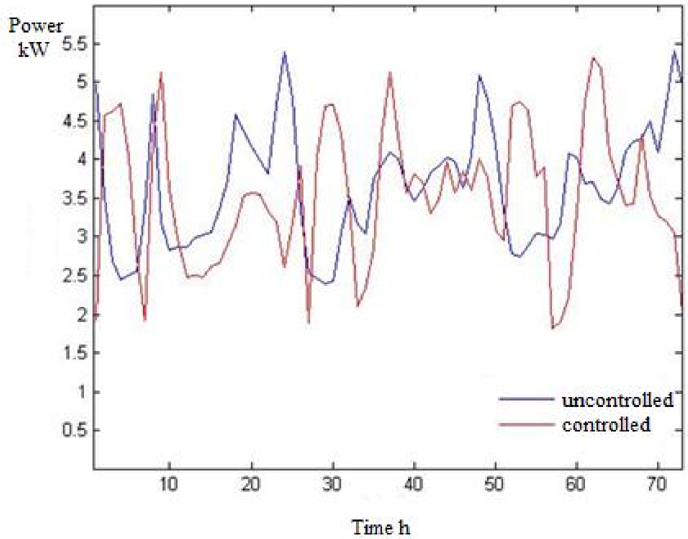

Fig. 5. Behaviour of loads in January of years 2010–2013. Years 2010-2012 (i.e. uncontrolled years) are modelled as the joined curve.

Differences between previous years (i.e. 2010-2012) and the controlled year 2013 can be seen from Figures 4 and 5. The curve of year 2013 is mostly under the curve of the previous years, which means that energy consumption has been more constant and lower. Figure 6 presents typical weekday in December of 2010-2012 for more accurate study. The steering algorithm was in operation in December 2012. The time of the peak load due to the water boiler has moved to the time when spot-price has been the lowest. In previous years boiler has switched ON about at 22.00, when the lower price period of night-time tariff has begun.

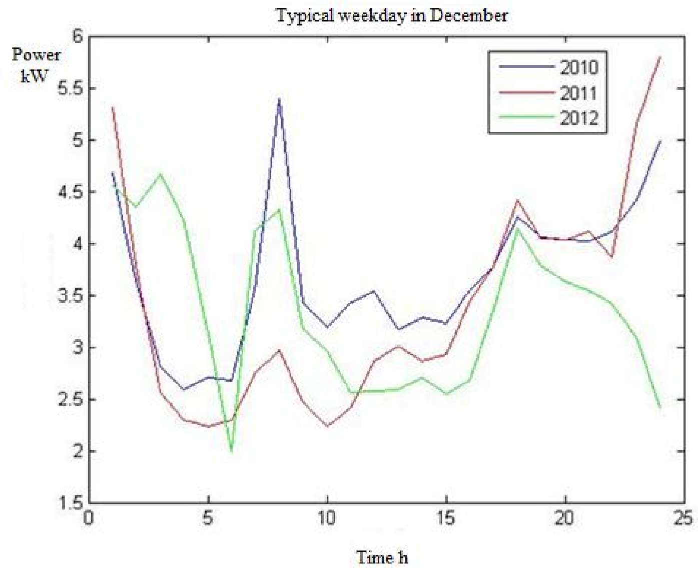

Fig. 6. Typical weekday in December 2010-2012

3.2 Effects of load control to load duration curves

Effects of load control can be examined also with load duration curves. The more constant load curves are the slighter has been the variation of electricity consumption. Exterior temperature corrected load duration curves from three December-February –time period are shown in Figure 7. Green curve presents controlled year’s energy consumption.

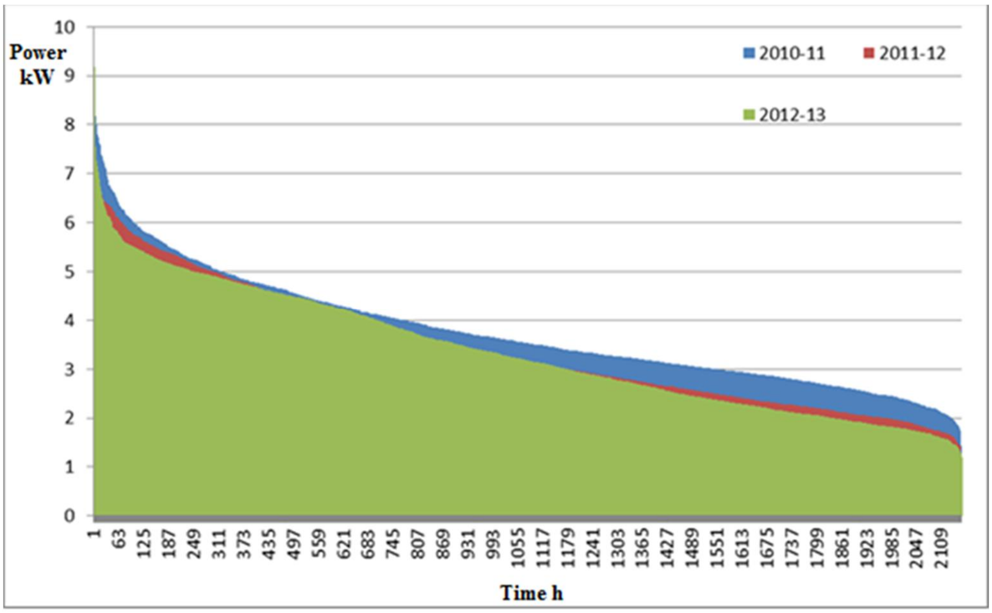

Fig. 7. Temperature corrected load duration curves between December-February in 2010-2013

Difference between these periods can be explained with power band controlling. Controlling the power level at 6 kW has meant a drop in load duration curve of 2012-2013 compared to the curve of 2011-2012.

Figure 8 illustrates load duration curves in February of years 2011-2013 with no temperature correction. Power band based controlling has meant fewer peak powers in the curve of February 2013. Peak power at 7-8 kW level has used only during some hours comparing to previous years. A small lump at hours 100-160 can be seen in the Figure 8. Load has switched OFF according to threshold value and switched ON when consumption has been less than 5 kW. Main principle of power band based steering algorithm is to switch loads ON immediately when consumption is less than the hysteresis value.

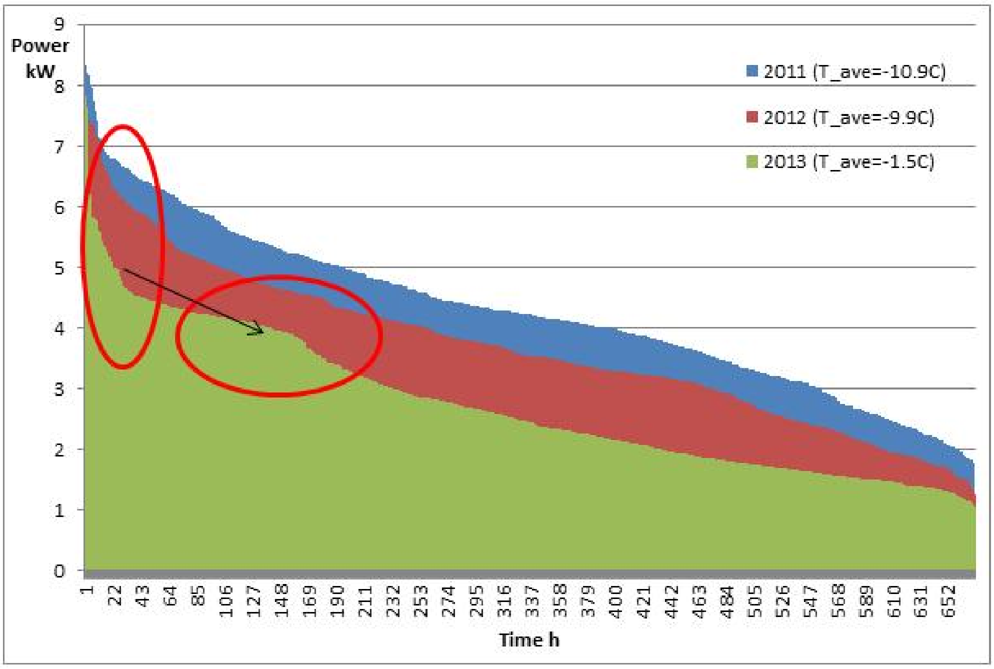

Fig. 8. Load duration curves of February of years 2011-2013

4. CONCLUSIONS

In this paper effects of demand response to loads of the pilot customer were studied with power band and spot-price based controlling. Consumption of the pilot customer was tried to hold under threshold value with power band based load controlling. When the consumption crosses the threshold value, controlled loads are switched OFF, and switched ON again when the consumption goes under the hysteresis value.

The time period including power band and spot-price based controlling were compared to the previous years' loads. In case of spot-price based controlled hot water boiler the effect of control operations can clearly be seen from the load curves. Activity of hot water boiler has moved couple of hours ahead to the time of the cheapest hours. Effects of load controlling were studied also by the load duration curves of the pilot customer. The number of peak power hours was decreased as a result of load controlling. Moreover, a small lump can be seen in lower power level of the load duration curve due to the load controlling algorithm.

BIBLIOGRAPHY

[1] A. Mutanen, M. Ruska, S. Repo and P. Järventausta, "Customer Classification and Load Profiling Method for Distribution Systems," IEEE Transactions On Power Delivery, vol. 26, no. 3, pp. 1755-1762, July 2011.

[2] Mutanen A., Repo S., Järventausta P., Customer Classification and Load Profiling based on AMR Measurements. Proceedings of the 21th International Conference on Electricity Distribution, June 2011, Frankfurt, Germany

[3] Rautiainen A., Repo S., Järventausta P., Mutanen A., Vuorilehto K., Jalkanen K., Statistical charging load modelling of PHEVs in electricity distribution networks using National Travel Survey data. IEEE Transactions on Smart Grid, vol.3, no.4, pp.1650-1659, Dec. 2012

[4] Saarinen E., Home Energy Management System in Enabling Power Based Network Tariff. Tampere University of Technology, M.Sc. Thesis, 92 p.