EXPERIENCES FROM SPOT-MARKET BASED PRICE RESPONSE OF RESIDENTIAL CUSTOMERS

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ABSTRACT

Time of use tariffs are already applied in large scale In Finland, but the electricity market prices do not any more follow such regular time pattern. Fast demand response is increasingly needed. Main results and experience from a recent price control project in Finland are explained here where spot-price based contracts were applied to about 10 residential customers with electric heating and hourly meters. Consumption and temperature measurements were installed and the heat dynamics modelled. Manual responses were observed and automatic methods for price response developed.

INTRODUCTION

In Finland storing electric space and domestic hot water heating is applied in large number of residential houses. It is widely utilised with fixed Time-Of-Use-tariffs, but the regular price variations between day and night have diminished from the electricity market prices, although TOU-pricing is still applied at customer level both in network tariffs and retail contracts. Some retailers offer also contracts based on hourly spot-prices even to small customers. Occasionally high price peaks are experienced in spot-market, sometimes even during the night time-zone. The need for fast demand response is increasing.

In Finland most big industrial controllable loads are already either responding to electricity market prices or reserved for emergency control purposes. The main potential to increase the price flexibility of demand is in electrical heated small customers, but the opening of the competitive electricity market and unbundling of businesses have so far made it difficult to connect small controllable resources to the electricity market.

The possibilities and barriers of applying day ahead spot-pricing to small customers were studied with field trials during the heating seasons 2004/05 and 2005/06. Test sites were subject to a tariff that transferred all spot-market price variations directly to the customer. The customers received the information on high spot prices via SMS-message or e-mail in the afternoon before the operation day on the basis of their preselected set value. The responses of the customers were observed.

Methods were developed for automating the price response and assessing its benefits. The methods include simulation, optimisation and heuristics. Simulation models were developed based on power and temperature measurements together with preliminary information on the building.

An optimisation method based on gradient optimisation, where the gradient is determined using the principle of Pontryagin, was developed and successfully applied with the simulation model. Simple automatic methods were designed based on the observed characteristics of the optimisation solutions. Here these methods are called heuristic methods. Different load control methods were compared by simulations using the data of winter 2005-2006.

ELECTRCITY MARKET

The electricity market in Finland has been opened to competition for all customers since 1998. The market is developing towards capacity shortage and dependence on imported electricity is increasing. The connection capacity to neighbouring countries is occasionally limited. Most of the time electricity spot market prices are relatively low and rather constant, but price peaks are higher and more frequent than before. Thanks to wide use of time of use tariffs and increase in international electricity trade the regularly repeating price differences between day and night have diminished. Also the match with price peaks and time of use time zones is poorer than before.

As an example we describe the situation on Thursday 19 January 2006. It was a cold winter day in Finland and in its neighbour countries. Import was necessary for meeting the electricity demand in Finland but the neighbour countries, especially Russia, had to limit their export to meet their domestic demand. Prices in the Finish spot market peaked very high in the early morning and then in the evening. In the national power balance time of use control made a step increase of over 900 MW at 22:00 o'clock. The two highest price peaks in the Figure 1 are on 19 January. The price in the Figure 1 and in the following analysis comprises spot-price, time-of-use distribution network tariff and taxes. Small retailer margin is not included, because it can be partly or totally in the fixed costs.

The settlement rules in the Finnish electricity market act were changed suddenly at the end of 2004 so that the commercialisations of the project results became infeasible. It became forbidden to use real measurements instead of load curves in the small customer settlement. Load curve based settlement removes all incentives to load control from the outside retailer to the locally dominating retailer that gets all the benefits of load control in its balance irrespective whose customers were subject to load control.

TEST SITES AND MEASUREMENT SYSTEMS

The test sites comprised two blocks of flats and ten small houses or apartments. Such test sites were selected that already had an automation system for measurement and control of the temperatures. Local distribution network companies installed AMR-systems based on hourly meters according to their normal routines and pricing. In test sites some new measurements sensors and a data collection system were added. Inexpensive wireless measurement system was interfaced to the remote units of a remote automation system that collected the measurements over ADSL communication.

All the small houses and apartments have heat storing electrical heating, a wood burning fireplace and electrically heated sauna. Test houses are the following:

– A detached house, its floor area is 200 m^2.
– A group of four detached houses with heat storing electrical heating and buying electricity together, their floor areas are 168 - 252 m^2.
– A row house comprising 5 apartments; they buy electricity separately and have floor area 120 - 155 m^2.

The blocs of flats provided homes for retired elderly people. The buildings are connected to the district heating network but washing rooms have also electrical floor heating. In addition this test site had also three cold storage rooms. However, in the following only the results of small houses are discussed due to the limited space of this presentation.

RESULTS

Manual customer response

Customer responses were observed through temperature and power measurements. In most cases the customers did not record their actions so it remains mostly unclear weather the reactions were due to prices or due to outdoor temperature.

The Figure 1 shows how the fireplace was heated in one house, when it was cold and prices were high. The electricity consumption of the house shows that time of use control is applied in the heating. This is a very typical consumption pattern with low consumption during the day-time and using space and hot water storage capabilities during night-time. In some test houses or apartments the fireplace was used rather regularly and in some others irregularly or only during very cold periods.

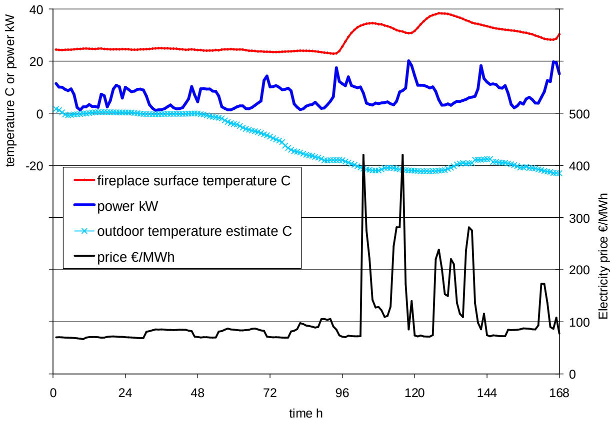

Figure 1. Use of fireplace on the week starting 15 January 2006 in a test house. Fireplace is heated when it is cold and the prices are high.

It is necessary to model the heat dynamics in order to find out the response of the fireplace to the power consumption. In the very beginning of the heating of the fireplace the increased airflow cools the building and increases the electrical heating slightly. As can be seen from the figure, the modern insulated fireplaces have long time constants and after warming up the fireplace releases heat to the indoor air so slowly that time series modelling of the power consumption tends to ignore most of it.

Dynamic temperature balance models

Simple models for the dynamic heat balances of the buildings were developed based on preliminary information on the buildings and on measurements made during 2004 and early 2005. MATLAB System Identification Toolbox was used. The models developed were linear except for constraints and the effect of ventilation.

The state variables were the following lumped temperatures:

– temperature of the indoor air
– temperature of internal walls
– temperature of the outside walls
– temperature of the heat storing floors
– temperature of the heat storing fireplace
– temperature of the sauna
– temperature of the domestic hot water storage

Models with some other state variables were tried but abandoned. For example, parameter identification turned out to be very difficult, if the floors of the buildings were modelled separately. The reason for this is the nonlinear heat transfer between the floors.

The main uncontrollable input variables were outdoor air temperature and occupancy. The heating powers of direct heating, storing heating and domestic hot water heating were the controllable inputs.

In the Figure 2 the response of the model is compared with the measurement of another flat in the same row house. The time period is the same as in the Figure 1. The difference in the beginning is due to the fact that in the measured apartment the 2-time control is applied also on Sundays although the lower night tariff is applied on Sundays. The slow differences later are likely to stem from the fact that there were no large step changes in the temperature during the previous winter when the modelling data was measured. As a result the long time constants in the model are likely to be somewhat too short.

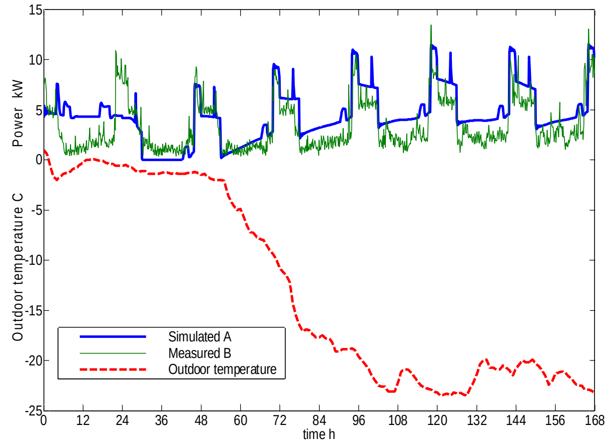

Figure 2. Comparison of the model response of apartment A to the power measurement of apartment B based on TOU-control.

Methods for automatic price response

Determining the best response of the house to price variations is an optimisation task, where the objective is to minimise power purchase costs while maintaining comfortable indoor conditions. An optimization method was developed for the purpose and implemented in MATLAB. The method is based on the generalized reduced gradient method with the gradient calculated from the adjoint state using the principle of Pontryagin. The approach is explained in detail in [1]. Time step of 15 minutes was used in the optimisation. In the simulations optimisation period of one week was used without excessive computation times. For spot price control optimisation period that covers the next day is usually sufficient and the additional benefit from longer periods is rather small.

Figure 3 shows an example of the heating powers given by the optimisation method during the highest price peaks shown in the Figure 1. Heating during the evening price peak is completely avoided by the use of storing heating in the middle of the day.

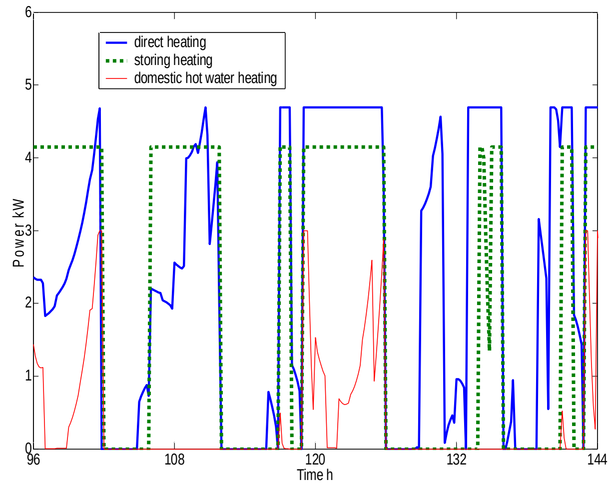

Figure 3. Optimised heating during 19 and 20 January, the price peak days of the Figure 1. Simulation.

A more simple method was developed by imitating the properties of the optimised responses. We call it as the heuristic method.

The developed methods were compared in simulations with the traditional Time of use (TOU) control method that was applied in the real buildings.

Simulated benefits of automatic price response

The benefits of different methods were compared by simulations. The simulations covered 16 consequent weeks in winter 2005-2006. The results for a row house apartment are shown in Table 1. The benefits concentrate on times when price peaks are high and outdoor temperatures are low.

Table 1. Comparison of different control methods when spot price based tariff is applied. (TOU = Time of Use Control)

	energy	variable cost
16 weeks	kWh	€
optimised	9262.24	759.30
heuristic	9332.55	763.70
TOU	9294.49	807.15
no control	9215.10	849.00
week 3/2006	kWh	€
optimised	749.27	63.47
heuristic	768.37	65.45
TOU	748.68	79.34
no control	735.53	82.92

It can be seen from the Table that TOU-control decreases the costs about 5 % compared to no-control situation. Further 5-6 % saving can be obtained by optimised spot-price based control. It has to be noted that the additional benefits of using fireplaces or changing the other use of electricity by the customers is not taken into account in the benefits shown in the Table 1.

The benefit of optimisation for the detached house was bigger due to its bigger size and energy demand, but the benefits normalised to the size were slightly smaller. The reason for this may be the relatively bigger heat storage capacity of the detached house.

Identified possibilities and barriers

Barriers and potential for price response were identified.

The main barriers identified were
- electricity market legislation regarding small customer retail, metering and settlement,
- high cost of needed consumption metering and their building automation connection and
- the lack of adequate, well functioning and reliable energy management automation in the residential buildings.

Actions recommended to remove the barriers for price control include the following:
1. Change the Finnish electricity market legislation to allow small customers (3x63 A and below) and their retailers to choose settlement be based on real hourly measurements instead of the now compulsory load curve based settlement. In Sweden this is already possible so this change will also help in harmonising the Nordic electricity retail market.
2. Create common national minimum requirements for remotely readable consumption metering. These requirements should include functionality needed for demand response and load control.
3. Uniform and reasonable pricing of the metering services should be required. In Finland each DSO has metering monopoly and sets it tariffs at its own will only.
4. Remotely controlled Time-Of-Use control should be made more flexible than before so that heating during the highest price peaks as well as unnecessary controls can be avoided.
5. Energy management automation of small houses should be improved to take into account the actual hourly variations of energy prices. Energy optimisation, tuning and reliability of the control circuits as well as installation of the temperature sensors are too often inadequate and limit the benefits.
6. Business models should be developed to enable efficient interfacing of the energy market and its small customers as well as fair sharing of the benefits. These should cover also direct load control in addition to price control.

SUMMARY

Serious barriers to small customer price control were identified. However, methods and device costs can be reduced acceptable in mass installations, if large homogenous market area can be established. Even the needed optimization methods can be included in the automation systems. On the other hand, some critical barriers are still related to the electricity market legislation and practices including the following:
- the legislation on small customer settlement
- metering tariffs and requirements differently set by each DSO.

Other important barriers are related to building automation and energy management of small houses. It is seldom feasible to invest only on the price response implementation unless the energy balance of the target site can already be observed and controlled.

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