MARKET PRICE BASED CONTROL OF ELECTRICAL HEATING LOADS

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ABSTRACT

Smart metering systems were improved to support dynamic control of electric heating. This enables automatic control on the basis of day-ahead market prices, for example. The current remotely read electricity meters have a two-way data transfer connection, a load control facility, and often in two-rate time of use tariff sites also some connected controllable load. The objective was to develop a load control model for harnessing the features of the current meter reading systems to better serve the needs for dynamic responses in the electricity market and networks.

This paper describes the solution developed by Helen Electricity Network and its partners. Initial results of the first field tests of this system are described. In these the control is based on the hourly electricity prices of the day-ahead spot market.

INTRODUCTION

Background

In Finland and in Helsinki 2-time tariffs for electrical heating have been successfully applied since 1964. In large scale use they level out the national load curve thus reducing costs and emissions from electricity generation. In the competitive day-ahead electricity market the regular price variations between day and night have diminished, but very high price peaks, over 30 times the average price, and also very low prices occur occasionally in the day-ahead and intra day markets. Sudden high price variations are expected to occur also in the future, because the potential for inexpensive responsive generation and demand side resources is limited while the need for them is expected to increase due to several reasons such as planned increases in wind power and nuclear generation. So there is an increasing need for dynamic demand response.

Objective

The objective is to enable new more dynamic load control methods to replace the traditional static time of use tariffs and controls.

THE PROBLEMS

The main problems to solve were the following:
1) Operating and message exchange model for the relevant electricity market actors was missing.
2) Commercial smart metering systems did not readily support such dynamic load control models.
3) The benefit potential and performance of different potential price control methods needed further analysis, comparison and verification.

APPROACH

We study the utilization of remotely read meters in the control of electric heating on the basis of the day-ahead market price and develop related solutions. This includes
1) studies regarding modelling, benefit potential and selection of the target customers (analysis and simulations based on data on load properties as well as consumption measurements and modelling and simulation results of some earlier projects of VTT and Helen Electricity Network),
2) development of the operating model for the purpose including message exchange between the relevant market actors,
3) development of support for this operating model by two smart metering system manufacturers into their systems,
4) verification in laboratory tests,
5) verification in field tests.

SOLUTION

The load control system model

Traditional model

Consumers use electricity for appliances, for the heating of living spaces and for obtaining hot water, for example. It is not significant for the customer when his/her home's heat storage is heated as long as there is always enough heat in the storage. Thus it is desirable that heating of the heat storage is carried out at a time when electricity is cheaper. For this purpose two-rate electricity tariff control is used as a basic product of the Finnish electricity market. The key features of the product are reliability and inconspicuousness of control. With the exception of fault situations, there is no need for the electricity user to intervene in the operation of the heating system. The traditional two rate tariff is controlled based on time and not dynamically based on electricity price.

New model

The new system now under development must offer the same reliability and inconspicuousness to the electricity user as with the two-rate electricity product, and in addition support dynamic load control functionality for various purposes. In order to be able to meet the requirements, the system must operate fully automatically so that the consumers do not even notice it.
Figure 1 presents the hierarchical principle, in which load controls are carried out by the electricity retailer as and when necessary.

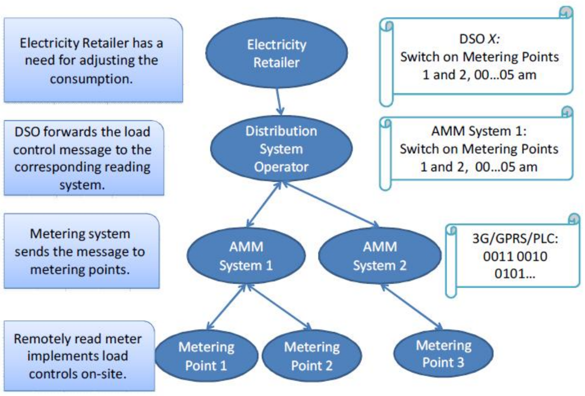

Figure 1. The hierarchical principle of the load control system model [1]

In Figure 1, the electricity retailer or other corresponding operator first determines and reports the load control need for the next 24 hours. The Distribution System Operator (DSO) of the relevant metering points receives the control command and forwards it to the correct metering systems (Advanced Meter Management systems, AMM systems) according to the metering site ID. The metering system receives the message and sends it to the remotely read meters for implementation of load controls. The model only takes a stand on the message format in the interfaces, not on the medium that the message is transmitted with.

The operating model developed enables many types of load control functionalities for various purposes such as switching loads on and off, limitation of power, load shifting and controlled charging of electrical vehicles; the model supports control actions for power network and system operation, as well as for electricity markets. It offers a mechanism to implement demand response fast in large scale and with modest costs where modern smart metering systems and time-of-use loads readily exist. Controlling the existing time-of-use loads based on electricity market price in only one of the possible applications. There the benefits gained from dynamic load control are substantial compared to the investment while the consumer's comfort is not compromised.

Pilot system

Helen Electricity Network's current systems and equipment in production use are used as a test platform for the load control system. An objective was that there is no need for purchasing separate equipment or systems by the electricity distribution network company nor the consumer.

Time of use controlled sites as a pilot

Helen Electricity Network's controlled night-time product was examined. It applies ripple control like commands calculated based on the heat demand and time. The new system adds taking the price information of electricity into account.

Loads are controlled to low-tariff night-time in electrically heated houses. The sites have a heat storage tank with water circulation. They are full storage electric heating system, with a possibility of supplementing it with other heating methods. The input powers of the systems vary between 20 and 50 kW. Currently, 1/3 of the input power is controlled on in a fixed way based on time, and the remaining 2/3 of the input power of the system is controlled on according to the outdoor temperature. Heating load switch-off takes place by thermostat controls or when the time frame closes. The heat storage in the system is charged depending on the outdoor temperature for 3–10 hours during 21–07.

In the new system, the entire load of the heat storage tank is transferred behind a single control. The more favourably-priced times of the night are fully utilised when heat storage is not started with partial power in the hours towards the midnight, which is a more expensive time on the average.

Algorithm for heating controls

The initial data of a system controlled according to the price of electricity and heat demand is obtained as an hourly time series from the measurement data management system (Generis). Generis contains diverse calculation functions for measurement series, but for the time being it cannot be used for forming a conclusion function for ending the load controls. A separate minor software item that meets the heating need starting from the cheapest hours was made for the pilot project. The software reads the hourly price information obtained from Generis, as well as the heat demand, and prints out to a file the cheapest heating periods as control commands. The heat demand is determined as a linear function of the average temperature for the previous 24 hours. The time frame of the heating period is smallest when the average temperature is +13 C, at which time the heating period is three hours. When the temperature is below -27 C, the heating period is a full 10 hours. If it is not possible to define the heating period on the basis of the initial data, the system safeguards the heat demand by controlling the heating to switch on for the duration of the entire night-time tariff (10 h).

The timing of load controls for the heating period is illustrated in Figure 2. Dynamic control utilises the more favourably priced hours of the heating period while meeting the heat demand completely.

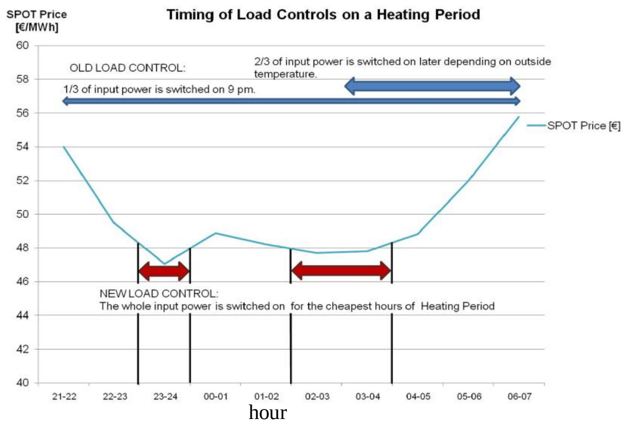

Figure 2 The principle of the timing of load controls for the heating period [1].

Processing of the information

The load controls for the next 24-hour period are concluded every day of the year. The exceptional trading rhythm of the electricity exchange on public holidays and at weekends does not result in deviations in the system because the spot price information for the next day is always known under normal circumstances. Similarly, the average temperature of the previous 24 hours is calculated from the most recent measured temperature data.

The initial data is recorded daily in the file server as hourly time series in XML format (eXtensible Markup Language). A small pre-set program is used for automatic processing of information, calculating the average temperature for the previous 24-hour period from the hourly series and concluding heating time n in accordance with the linear heat demand function. According to the heat demand, heating is switched on for the cheapest n hours of night-time tariff. The control times are printed out as an XML file in a specified form to the file server. The file contains the controlled metering points and control times.

The control file is sent to desired reading systems through the WebServices interface. Each reading system processes the control messages in its own way and forwards the data to the meter along a normal two-way data transfer connection. If the control data is not transferred all the way to the meter, a default control function is performed on the meter in order to meet the heat demand at any time of the day or night.

The principle of the data processing flow is presented in Figure 3.

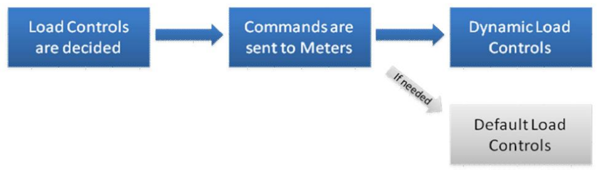

Figure 3 Main steps of data processing [1].

BACKGROUND STUDIES

Previous measurements

The electricity consumption of one of the targeted houses had been measured in detail for a period of three years for other research purposes [2]. Thus power measurements as shown in Figure 4 were readily available. The load control method is as described in the previous page. The power peaks in the early hours of the morning are due to the fact that the thermostat keeps the temperature of the heat storage tank at the default charge set point value. The power demand follows the outdoor temperature with a delay of roughly one day.

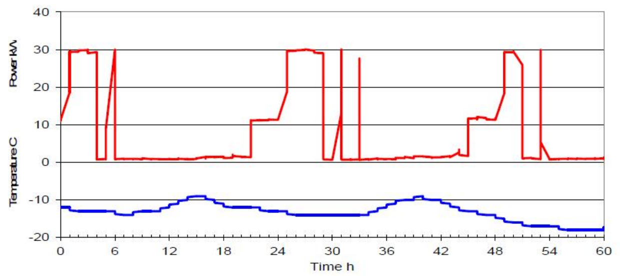

Figure 4 An example of the power consumption and power measurements of a house with full storage heating house in 1997 [1].

Simulations

A simple dynamic model of the house was built based on the previous power measurements and data on the building properties (volume of the house 640m^2, volume of the heat storage water tank 3.7m^2, etc.) Different price control methods were compared with simulations [3]. The methods were compared also for partial storage heating. Our earlier comparison explained in [4] provided the starting point and tools for the comparison. The performance of the methods was compared over the week 3/2006, because then the variations of the electricity price and outdoor temperature were exceptionally good for the purpose. The main result can be summarized as follows. 1) In sites with partial storage, achieving full benefits requires real-time optimisation, but in a full storage site almost full benefit potential is achieved with the simple dynamic price control method described here. 2) Longer simulation period is needed to make an accurate quantitative comparison.

Analysis of the impacts to the network

The impact to the electricity network is not any bigger than with the traditional time of use method [5].

Cost-benefit analysis

The operating costs and benefits are discussed in [1] The costs of system development and research were not analysed. The annual costs of data transfer was estimated to be less than 1€ per metering point, and the relative benefit in the costs of energy use, achieved on the basis of simulations with spot prices of 2008, would be 3–15% depending on the heating system of the site [6]. It was estimated that over a period of ten years, the theoretic discounted yield on a system investment of some thousand € is €750,000 with a five per cent imputed interest[1]. The beneficiaries depend on the pricing structure of the electricity transmission and sales product.

TESTING AND VERIFICATION

System test

The meters were installed in a laboratory test environment made to closely correspond with the actual operating situation with the exception of its physical location. The meters were controlled and read with the production smart metering system with a pre-set load in order to be able to verify the functioning of controls from the hourly energy series in accordance with a normal reading process. Based on the tests some problems with the smart metering systems had to be fixed. After that the laboratory tests were successfully completed in week 24/2010.

The first field test

The system is being installed in eight metering sites of Helen Electricity Network. Testing of the system under a normal operating situation continues through the heating season of 2010–2011. Participating electricity retailers observe, comment and plan to implement the needed interface into their systems. The intent is that the tests will be continued in the next winter with some more houses and also by another distribution network operator, Vantaa Electricity Network.
The first metering point and house has been operating since 8 November 2010 and new sites are being added gradually. The system is working as planned. The electrical heating is applied when the prices at the spot market area are the lowest; lower outdoor temperature increases the heating energy applied thus meeting the heat demand of the house. Figure 5 shows this.

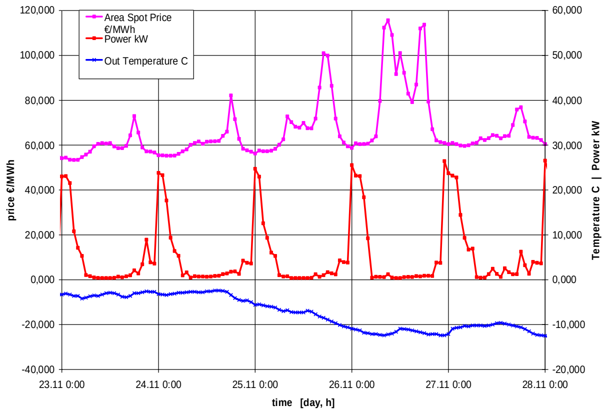

Figure 5 Field test measurements of dynamic load control based on spot market price

During one later week there were some small exceptions to the ideal behaviour. These need further analysis.

FUTURE VIEWS AND CHALLENGES

The automatic dynamic control solution developed is very economic in areas that need flexible resources and have both smart metering and substantial amounts of electrical full storage space heating or domestic hot water heating. The solution is also a clear improvement compared to fixed ToU control for other controllable load types.
Wide application of the solution requires the following:
- Integration of electricity retailers to the system.
- Adoption of the new model by more distribution system operators and smart metering systems.
- Recommendation, and later a common requirement, for adequate support for the automatic dynamic load control functionality by smart metering systems in national, European and international contexts.

CONCLUSION

Helen Electricity Network together with its partners developed a load control model for versatile implementation of various load controls meeting several needs. The introduction of the system needs only a modern remote reading system complying with Finnish Government Decree 66/2009, a program performing the algorithm and the connections to the systems of electricity retailers. The benefits are very good compared to the operating costs of the system, which are estimated to be € 0–1 per year per metering site.

Acknowledgments

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