RESEARCH REPORT

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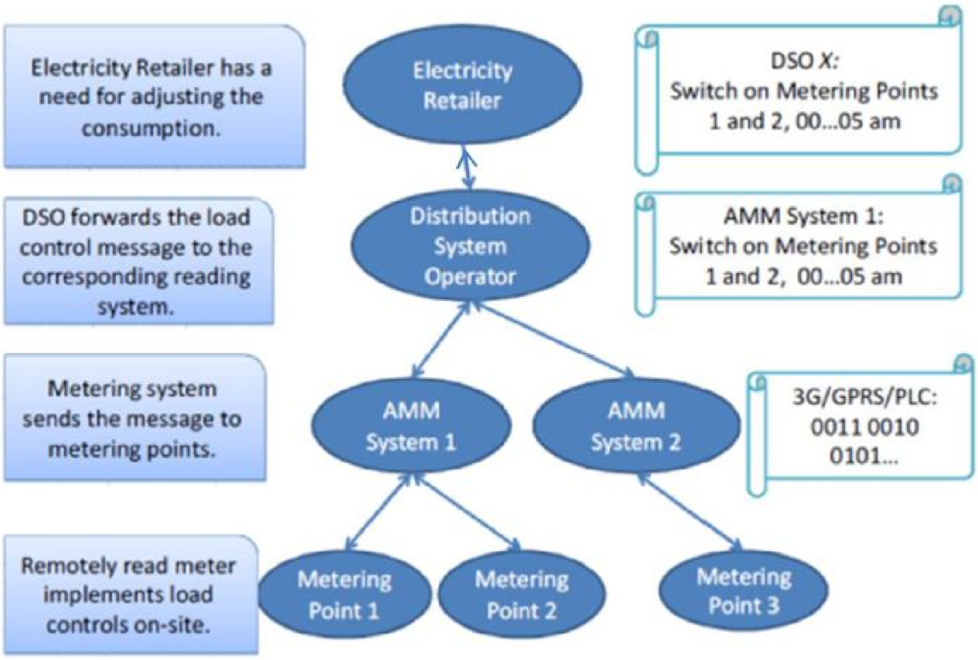

Plans for the second field test year on smart metering based dynamic load control

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Summary

Dynamic load control via smart metering systems was developed by Helen Electricity Network and partners to replace traditional static time of use control systems. This report reviews the results of the first field test winter and spring and the test plan for the second field test winter. The focus on the first field test winter was on verifying that the operating model and the systems work as planned, when the distribution network operator (DSO) is defining the control commands instead of the retailer. Because this succeeded, the focus of the second field test winter is on verifying that the integration to the electricity retailer works and to what extent the system can meet the needs identified by the participating retailers.

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Distribution (customer and VTT)
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Preface

This work was carried out in the Smart Grids and Energy Markets (SGEM) research program coordinated by CLEEN Ltd. with funding from the Finnish Funding Agency for Technology and Innovation, Tekes. In addition to the authors the following SGEM partners contributed to the report by reviewing or providing views or information:
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1 Introduction

Dynamic demand response is increasingly needed, because regular daily variations in the electricity market prices have diminished but very high price peaks occasionally occur. In addition, price volatility, also within a day, is expected to increase in the electricity market, because of power generation investments on big nuclear power plants and intermittent renewable energy sources.

Static time of use tariffs have been successfully applied in Helsinki since 1964. Their large scale application in Finland contributes to the diminishing of regular daily price variations, and improves energy efficiency and reducing costs of power generation. But it is not able to help with the dynamic price variations that are sometimes very high, even over 1000€/MWh.

The objective of our research is to enable new more dynamic load control methods to replace the traditional static time of use tariffs and controls. Thus an operating model for dynamic load control via smart metering systems was developed.

Two smart metering system manufacturers implemented the model into their systems. Also Helen Electricity Network Ltd. updated its related ICT systems to support the new operating model. Then the system was tested in laboratory tests and entered field tests at the end of 2010.

This report reviews the results of the first field test winter and spring and the test plan for the second field test winter. The focus on first field test winter was on verifying that the operating model and the systems work as planned, when the distribution network operator (DSO) is defining the control commands instead of the retailer. Because this succeeded, the focus of the second field test winter is on verifying that the integration to the electricity retailer works and to what extent the system can meet the needs identified by the participating retailers. So now also the uppermost layer in the Figure 1 is included in the tests. In addition the scale of the tests is substantially increased.

The system and the operating model were described by Seppälä and Koponen (2010), and Koponen and Seppälä (2010). Seppälä (2010) and Seppälä and Koponen (2011) wrote also in Finnish reports on the system developed. Related background studies include those by Uola (2001), Leksis (2009) and Koponen and Seppälä (2010). Detailed power measurements of one of the target houses were recorded by Pihala(1998) long before the field tests.

Figure 1 is similar to a figure in (Seppälä and Koponen 2010) except that the retailer also gets information from the DSO in order to know, to what extent the control actions succeeded. This may be necessary, when retailer participates in the balance market, for example.

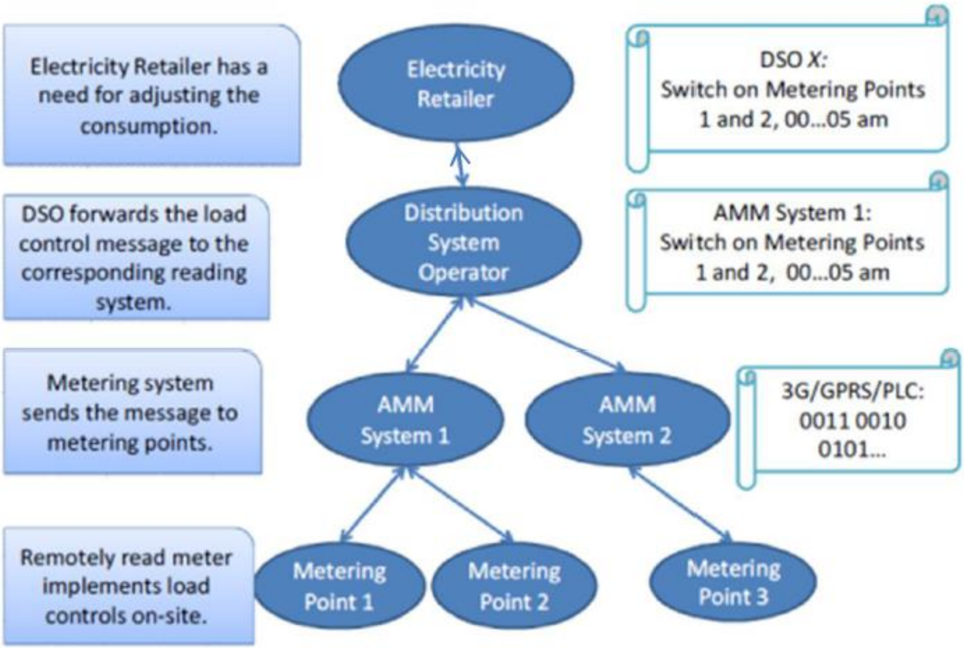

Figure 1. Overview of the system in field tests (based on Seppälä and Koponen 2010).

2 The smart metering based dynamic load control operating model

The main principles of the operating model are described by Koponen and Seppälä (2010) and in more detail by Seppälä and Koponen (2010). Figure 1 presents the hierarchical principle, in which load controls are carried out by the electricity retailer as and when necessary.

The electricity retailer 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 control actions.

The retailer calculates based on outdoor temperature the heat demand for the house. Based on it as well as on the electricity market prices, own market contracts and own balance forecast it then decides the hours for heating. Thus, according to the heat demand, heating is switched on for the cheapest hours for the retailer.

The operating model 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. Controlling the existing time-of-use loads based on electricity market price is only one of the possible applications.

The operating model includes a default control sequence stored in the smart meter. This will be applied, if the control command is not received by the meter, due to communication system failure or other reason. The operating model also supports sending control signals at regular times of the day as well as sending overriding ad hoc control command sequences.

3 The results from the first field test winter and spring

3.1 The objective, scope and approach

3.1.1 Objective

The purpose of the first winter field tests is to verify that the operating model and the system developed is ready for

- increasing the scale of the field tests and
- including in the field tests retailers that actively control the loads via the system developed.

3.1.2 Scope

The control signals were generated by the distribution network operator that was also a metering operator. In the first year field tests the retailer’s interface to the system was not tested.

3.1.3 Approach

We studied 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 included

- 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),
- development of the operating model for the purpose including message exchange between the relevant market actors,
- development of support for this operating model by two smart metering system manufacturers into their systems,
- verification in laboratory tests,
- verification in field tests,
- analysis of the field test results.

3.2 The test sites

All test houses were full storage heating houses. The first metering point and house have been operating since 8 November 2010. In the first field test winter there were two houses participating and in spring the number of houses included was six.

For example, the most important properties of a full storage heating house were:

- indoor volume of the house 640 m3
- volume of the heat storing water tank 3.7 m3
- max heating power for the heat storing tank 30 kW
- power of the electrically heated sauna 7.5 kW
- power of the electric cooker with oven 12 kW
- the same heat storing tank provides also hot domestic water.

3.3 Field test results

The very first field test results are from November 2010 and were reported by Koponen and Seppälä (2011), see Figure 2. 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. Later in 2010 some minor problems were observed and corrected such as occasionally too long non-heated time in case of certain price patterns.

1st January 2011 there was a daytime price dip, but as the heating control was limited to nigh time of the tariff this dip could not be utilised. See Figure 3 that shows the average consumption of two houses. If heating would have been applied during the price dip the resulting saving would have been about 1 – 1.5 € per house. Notice also the consumption peak in the evening of 1st January caused most likely by heating of electrical sauna and to some extent also due to sauna related increase in hot water consumption. The peak was during a very typical sauna time in Finland.

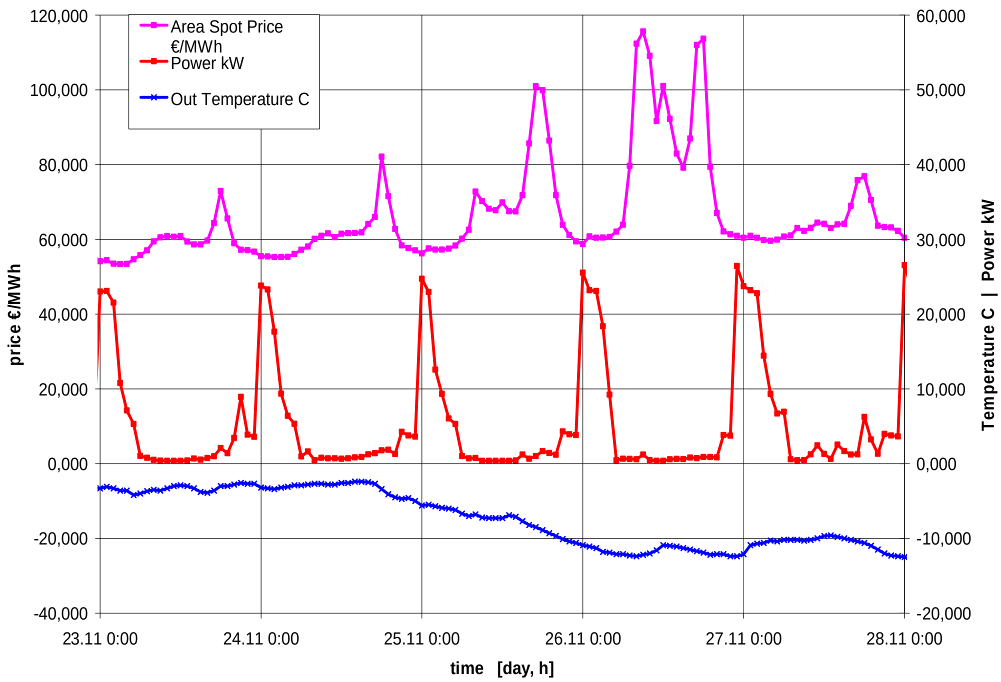

Figure 2. Results of the first field tests (Koponen and Seppälä 2011).

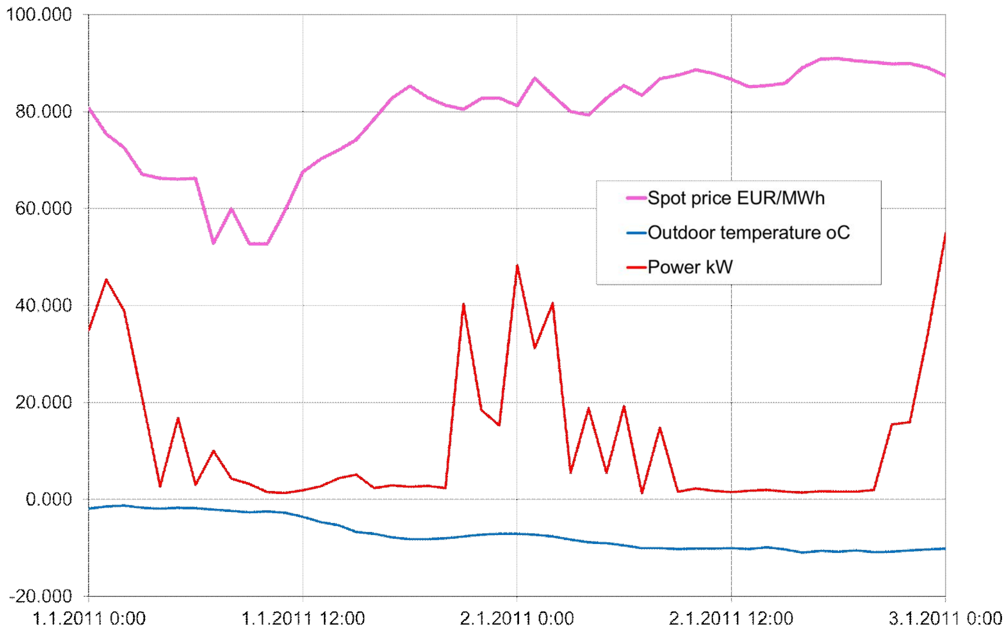

Figure 3. Heating control on was limited to night time so price dip was lost.

Most of the time the system behaved as expected and without any problems observable from the measurement. The overall behaviour is good in the Figure 4 that shows the summed power consumption of the same houses as in Figure 3 over a period of over one month. Heating was never on during the price peaks, but some low spot prices lost can be observed by zooming the Figure 4. This phenomenon is even clearer when the heating time is short during higher outdoor temperatures, see Figure 5.

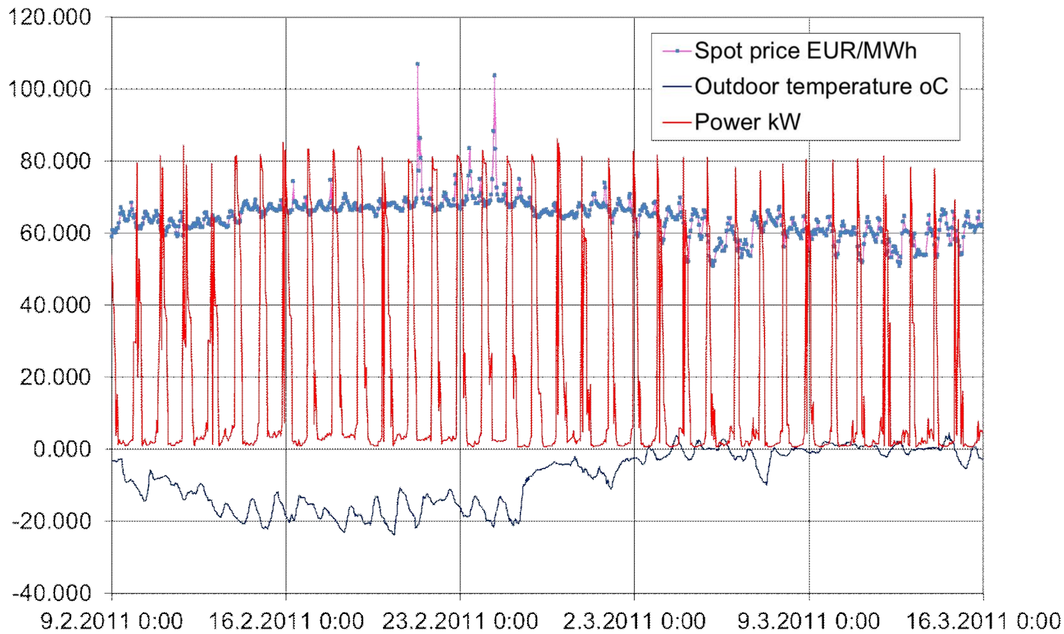

Figure 4.The system worked as expected during low temperature and price peaks

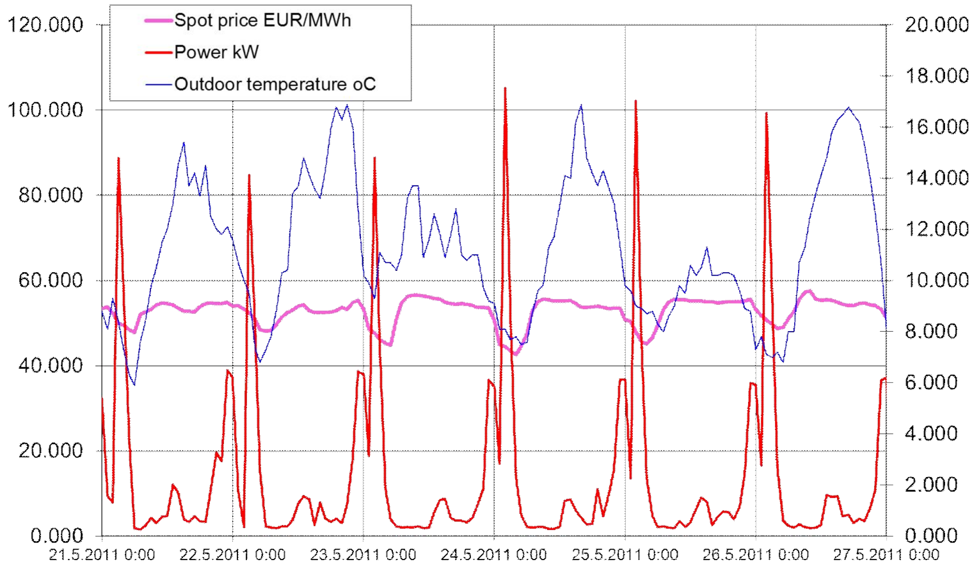

Figure 5.The system worked as expected also during higher outdoor temperatures

The dynamics of the dependence of 24 hour energy consumption on the average daily temperature was estimated from the measured average consumption of two houses. The first initial results still to be checked are the following. The best fit was achieved when the energy consumption was delayed by 21 hours compared to the temperature. The red line in Figure 6 shows the resulting least squares fitted line.

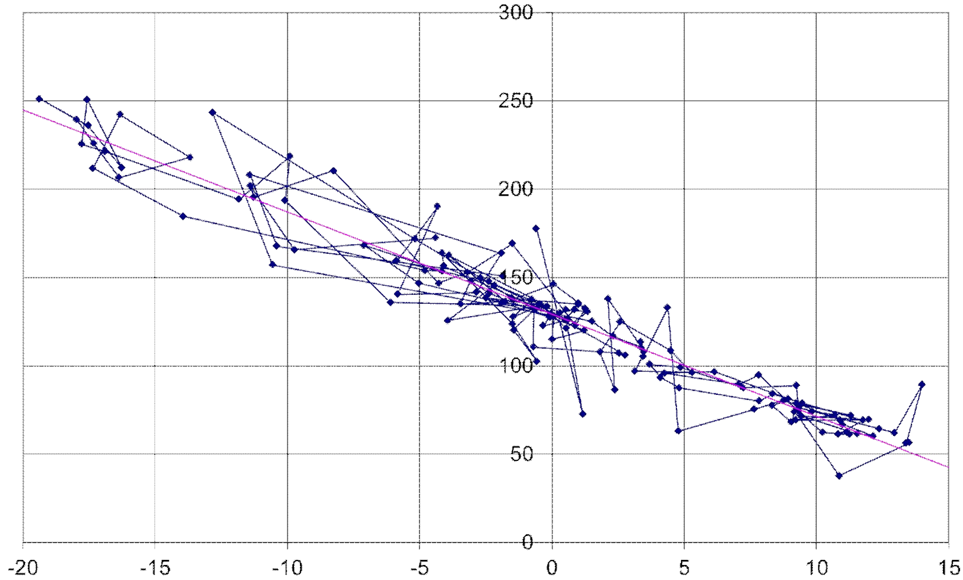

Figure 6.The temperature dependence of daily energy consumption on daily average outdoor temperature is good, when 21 hour time shift is applied. The points are connected with blue lines in time order. The red line denotes the fitted linear dependency.

It shows the data from 146 days in the beginning of 2012 and the fitted curve for the dependence of the energy consumption that is

$E_{24h}(t)$ = 129.3 kWh – $T_{24h}(t\text{-}21)$ 5.78 kWh/oC

Where

$E_{24h}(t)$	Energy consumption of the day (from 00:00 – 00:00)
$T_{24h}(t)$	Outdoor temperature average over 24 hours
t	Time in hours

Thus when load control signals are sent in the afternoon it may be best to use the weather forecast for the rest of the day to complement the temperature measurements so that the average daily temperature can be calculated ahead of time. Now the temperature used for calculating the heat demand is about one day older so there is some room for improvement. A more comprehensive analysis on predicting the heat demand and the control responses has been started and will be reported separately. It is planned to include comparison of some alternative ways to predict the heat demand. Accurate prediction of the control responses and the load are important for the electricity markets and smart grids.

4 Functionalities and testing needed for retailers

4.1 Important or challenging functionalities

Regarding utilisation of demand response by retailers using the smart metering based load control system of the DSO the following functionalities have been identified important and challenging so far:

4.1.1 Functionalities that need to be tested

Retailers need to know how well the following functionalities are supported by the system developed and being tested:

- Free definition of the controlled periods by the retailer
- Fast or instantaneous control by the retailer (For example, control responses within 15 minutes to one hour from sending the command)
- Timely information on loads and their responses to the retailer

4.1.2 Functionalities for other closely related services

Retailers wish that support for some closely related services is also tested including

- Remote connect/disconnect of customers
- Fault monitoring and reporting for the retailers and their customers

4.1.3 Functionalities that are needed but not supported by the system

There are functionalities that are needed by the retailers, but are not supported by the present system. These include:

- Possibility to send also price control signals or other extended information to the consumer. It needs to be analysed carefully to what extent it is possible and reasonable to implement these functionalities via smart metering systems. It may be better to implement expensive and advanced load control and customer information provision functionalities outside the regulated monopoly DSO. For retailers it is useful that load control commands can be sent via redundant communication channels.

- Provision of instantaneous or real time information on loads and their responses to the retailer. This target can be approached by developing 1) model based estimation of loads and responses and 2) communication solutions in the smart metering systems.
- Sending the same XML-messages via other communication channels to the controlled houses and their automation systems.

4.2 Testing of scalability and performance

In order to benefit from the load control system developed, it is important for the retailers to know the limitations of the performance such as the volume, reliability, predictability and latency of the response. The retailer needs information on how the scale of the system and the data communication system configuration affect the performance. Such information could, for example, tell how long time it takes for different system sizes (such as 10, 100, 1000, 10000 and 100000 controlled houses), when 50%, 90% and 99% of the target houses have received the control command and started their response.

5 Plans for the second field test winter

5.1 The objective, scope and approach

5.1.1 Objective

In the second field test year the objectives are focused on the point of view of the electricity retailers and are the following:

- verification of the operating model and system, when electricity retailers control the loads,
- getting experience on how the electricity retailers control the loads,
- learning what the electricity retailers need from the system,
- learning more about the data communication needs between the system and the retailer,
- providing background information for identifying the limitations and performance of the system so that the retailer knows the volume and response time that the system and the DSO can implemented,
- getting feedback for developing the system and its installation, usage and maintenance to be suitable for large scale rollout,
- getting initial information on the scalability of the solutions and on the impact of the scale to response time and other service level aspects and
- demonstrating and validating the suitability of the operating model for full scale piloting leading to large scale rollout.

Some possibilities to improve the system have been initially identified. Verifying possible improvements is also an additional objective, but only to the extent such improvement possibilities can be designed and implemented in time. Otherwise verifying those improvements will be left to the following years. Applying also weather forecasts to demand prediction is an example for such an improvement. During the second field test winter the number of houses included allows only very limited testing of the scalability of the system.

5.1.2 Scope

The operating model and the system developed are studied in the context of the existing electricity markets in Finland. The retailers can use either their existing tariffs or develop new tariffs that better utilize the possibilities of the new operating model. It would be good, if both options are included in the tests thus allowing comparison when analysing the results. For example, the retailer could launch a product were the use of heating is not limited to night time, if there is a daytime price dip low enough to compensate also the related cost increase due to daytime distribution tariff.

The DSO must check that it can implement the control actions requested by the retailer and inform the retailer, to what extent the requested control actions can be implemented. For example, the need to curtail control actions might result from network constraint violations or even from failures in the smart metering system. In these field tests the focus is on the technical aspects of the interactions between the retailer and the DSO, and the development and testing of new market rules regarding such curtailments and related compensations is now outside the scope. Only some observation and analysis of the network impacts of the control actions is within the scope.

Sensitive business knowledge of the electricity retailers is outside the scope of this field test. For successfully completing these field tests it is not necessary for the retailers to tell how they use this new flexibility in managing balance, maximising profits and minimising business risks. Development of new innovative tariffs is also mainly left to be developed later by the retailers.

5.1.3 Approach

Field tests will be conducted with a group size that has some statistical relevance. This means some tens of houses. When the number of test sites providing hourly measured data has increased enough, a reference group in traditional TOU use control will be established and measured for comparison. This will probably prove valuable when analysing the results or when studying customer acceptance and experience.

Response time and response reliability will be monitored in order to better understand how the scale of the system affects them.

Also the impact of the control actions on the network management will be monitored and initially analysed. Helen Electricity Network has some tools for this from their other research projects. A more detailed plan for this part will be defined along the progress of the work based on the initial results.

5.2 The test sites

The target houses are full storage heated small houses in Helsinki. In some houses the same storage tank is used both for space heating and for heating domestic hot water. In some houses one tank is used for both purposes. To the extent possible, we also consider inclusion of houses with heating systems different from full storage electrical heating, such as partial storage heating and heat pumps.

The new dynamic control approach is applied to houses that already have the needed internal wiring for Time of Use control. Thus the new dynamic control actions are implemented via the readily existing load control wiring. On one hand new wirings in the houses are not needed. On the other hand many houses and their wirings are old and in some houses there may be something that may not work properly any more.

5.3 Situation at the end of 2011

The weather in December 2011 was exceptionally warm which limited the possibilities for testing. At the end of 2011 some tens of houses were connected to the system and the application of control signals starts in January 2012.

5.4 The test plan

5.4.1 Gradual adding of new houses to the experiment

New houses are gradually added to the system. First the house wiring is connected to the load control outputs of a smart meter. Then there is a testing period with static Time-of-Use control and after that dynamic load control is applied. Fast large scale transfer to dynamic load controls is not yet done, because experience on possible problems and detecting and dealing with them is needed first.

5.4.2 Data collection and analysis

For each house included in the field test we plan to record
- measured power consumption
- measured outdoor temperature in the region, preferably at two or three measurement points
- the control signals and default control pattern applied
- possible failures in sending the control signals (reason, where, when)
- possible major changes in the heating system or usage of the building, if possible (e.g. if there is renovation or if heat pumps are introduced)

Based on the data recorded we analyse the control timing and the responses to it and to outdoor temperature. Then grouping of the houses is considered and the combined response of groups of similarly controlled houses are analysed.

5.4.3 Demand and response prediction

Also needs and possibilities to update demand and response prediction models are analysed based on the results. When dynamic load control is applied in large scale it becomes important to have accurate demand and response prediction for balance management needs, for securing adequate heating of the houses in all situations, and for DSO needs.

5.4.4 Customer experience and energy displays

Three energy displays located at customers' premises and there is a plan to collect experience from the customers regarding the displays and also their experiences regarding the dynamic load control. These are reported separately and are not discussed here.

5.5 Validation plan

The validation of the field tests includes the following:

- Analyse how well the power consumption is utilising the lowest daily prices in the electricity market and avoiding the price peaks.
- Continue the tests in order to verify the accuracy of demand prediction and the performance of the load control system and its data communication solutions.
- Compare measurements with reference groups, when possible.
- Update a simulation model of a typical house and compare field test results with simulations.
- Compare test results with test results reported in the literature.

5.6 Message harmonization

Work regarding harmonization of communication data models within SGEM and with IEC CIM will be continued. Harmonised data models are necessary to enable large scale deployment of the operating model and systems developed.

6 Conclusion

Field tests regarding dynamic load control based on smart metering are continued and gradually expanded. For large scale adoption of dynamic demand response it is important that both inside and outside project SGEM most DSOs in Finland start to provide for the retailers the dynamic load control functionality and the interface to it, and also retailers start to use them. The field tests aim to validate and demonstrate to retailers and DSOs that the operating model and the system can work as needed. They also provide feedback and experience needed for further development.

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