TR A6357

Automatic Demand Response referred to electricity spot price Demo description

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May 2006

TECHNICAL REPORT

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Enterprise No.:
NO 939 350 675 MVA

SUBJECT/TASK (title)

Automatic Demand Response referred to electricity spot price. Demo description

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CLIENTS(S)
Statnett SF / Enova

TR NO.	DATE	CLIENT'S REF.	PROJECT NO.	
TR A6357	2006-05-24	Inge Vognild / Jens Musum	12X345.06	
ELECTRONIC FILE CODE		RESPONSIBLE (NAME, SIGN.)	CLASSIFICATION	
060301133638		Gerard Doorman GD	Unrestricted	
ISBN NO.	REPORT TYPE	RESEARCH DIRECTOR (NAME, SIGN)	COPIES	PAGES
82-594-3065-7		Petter Støa PST	19	33
DIVISION		LOCATION	LOCAL FAX	
Energy Systems		Sem Sælands vei 11	73 59 72 50	

RESULT (summary)

This report presents background, technical solution and results from a test project (Demo I) developed in the DRR Norway project. Software and technology from two different vendors, APAS and Powel ASA, are used to demonstrate a scheme for *Automatic Demand Response* (ADR) referred to spot price level and a system for documentation of demand response and cost savings.

Periods with shortage of energy supply and hardly any investments in new production capacity have turned focus towards the need for increased price elasticity on the demand side in the Nordic power market. The new technology for Automatic Meter Reading (AMR) and Remote Load Control (RLC) provides an opportunity to improve the direct market participation from the demand side by introducing automatic schemes that reduce the need for customer attention to hourly market prices.

The *low prioritized appliances*, and not the total load, are in this report defined as the *Demand Response Objects*, based on the assumption that there is a limit for what the customers are willing to pay for different uses of electricity. Only disconnection of residential water heaters is included in the demo, due to practical limitations.

The test was performed for a group of single family houses over a period of 2 months. All the houses were equipped with a radio controlled "Ebox" unit attached to the water heater socket. The settlement and invoicing were based on hourly metered values (kWh/h), which means that the customer benefit is equivalent to the accumulated changes in the electricity cost per hour. The actual load reduction is documented by comparison between the real meter values for the period and a reference curve. The curves show significant response to the activated control in the morning hours. In the afternoon it is more difficult to register the response, probably due to "disturbing" activities like cooking etc.

Demo I shows that load reduction referred to spot price level can be done in a smooth way. The experiences from the demonstrator will now be used in a test case involving contracts between a Supplier of energy and smaller industry and commercial end users. The expected accumulated load reduction at the contracted price levels will in this follow up case be included in the Supplier's Elspot bidding.

KEYWORDS

SELECTED BY AUTHOR(S)	Price elasticity	Low prioritized appliances
	Demand Response	Remote Load Control

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1 INTRODUCTION

This report presents background, technical solution and results from a test project (demonstrator) developed in the DRR Norway project, which has been run in parallel with the international IAE/DSM Annex XIII “Demand Response Resources”, also called the DRR project[1] [1].

The objectives of the DRR Norway project are to:
1. Provide input to and exchange experience with the international DRR project
2. Demonstrate Norwegian technology and market based solutions for Demand Response (DR)
3. Evaluate the value of DR in the Norwegian Power System

The following two demonstrators where originally defined
- Demo I: Automatic load reduction when spot price exceeds a predefined limit
- Demo II: Remote load control of aggregated smaller loads in the Balancing Market

This report describes the main principles, the technical concept and the results from Demo I. Demo II was not completed due to technical and organisational difficulties. A description of the ideas behind and the experiences from Demo II is documented in a separate Memo in Norwegian [2].

The original goal of Demo I was to establish a concept for automatic reduction of *low prioritized* consumption if and when the spot price exceeds a predefined and contracted price level. The main benefits from this scheme are related to high priced periods, caused by shortage of production capacity. Due to low and stable spot prices in the test period, the goal was changed to demonstrate automatic load reduction in *periods with expected high price*.

[1] The DRR project was started April 2004 and will be terminated September 2006. The US company RETX is operating agent and the project involves experts from 12 countries.

2 BACKGROUND

The tight peak power balance, periods with shortage of energy and hardly any investments in new production capacity have turned focus towards the need for increased price elasticity on the demand side in the Nordic power market. The bid curves in the day ahead market (Elspot) are rather steep for higher prices, which means that elasticity is nearly absent. There is in fact a danger that price setting can fail in a bottleneck situation combined with extreme shortage of production capacity.

Previous studies have shown that a considerable part of the load is reducible with duration from one to a few hours. The potential for Norway is in the DRR project estimated to ~4200 MW in the Commercial and Industrial sector and ~2450 MW in the residential sector [3]. In total this amounts to ~20 % of the peak load. The challenge is to release this potential in the power market.

The new technology for Automatic Meter Reading (AMR) and Remote Load Control (RLC) provide an opportunity to improve the direct market participation from the demand side by *introducing automatic schemes that reduce the need for customer attention to hourly market prices*. The Nordic power market is settled on an hourly basis, which implies that hourly metering of the consumption is needed to obtain customer benefit from short term changes in demand.

The Distribution System Operator (DSO) is responsible for the metering of electricity in Norway. Hourly metered data is collected via different kinds of AMR systems and stored in the Meter Value database (MVDB) and/or in the customer information system (CIS). Several AMR systems do also include remote controlled switches that can be used for disconnection and reconnection of selected appliances. In this project a separate radio based system is chosen for the RLC scheme in Demo I. Note that this system is established in parallel to the AMR system, which is needed for collection of the hourly metered data. See Figure 1.

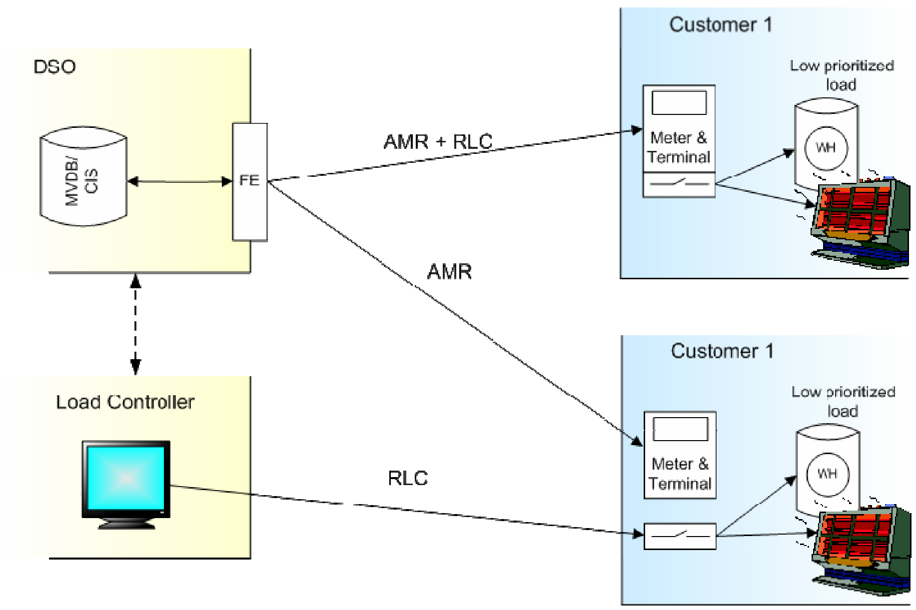


Figure 1 Alternatives for AMR and RLC.

3 DEMAND RESPONSE IN THE NORWEGIAN POWER MARKET

With exception of minimum volume requirement there are no restrictions with regard to demand side participation in the organized markets: Elspot and the Balancing Market[2] (BM), operated by the Nordic Power Exchange (Nord Pool) and the TSO (Statett SF) respectively.

The demand response in the spot and the Balancing markets has different characteristics:

- Load reduction in the spot market is initiated by the 24 hour spot price setting for the day ahead. The Elspot prices are published from Nord Pool around noon, which means that the potential DR is known from 12-36 hours before the hour of operation.
- Load reduction in the Balancing Market is initiated by call from the National Control centre when steady frequency / time deviation occurs in real time operation. Requested regulation has to be performed within 15 minutes.

The demand side participation in the day ahead market is so far characterized by price independent bids mainly caused by the substantial portion of fixed price contracts to the end users.

The Reserves Option Market (ROM) [4] introduced by the TSO in 2000 has been a catalyst for end user involvement in the BM. This product represents a kind of medium term ancillary service market where both producers and consumers are allowed to bid in reserves. The *new* element introduced by this product is payment for availability, which in this context implies an obligation to bid load reduction into the BM for predefined hours of the day during the contract period. With this new market arrangement the TSO has succeeded in including a considerable share of reserves from the demand side. As a consequence load reduction from “power intensive industry” like paper mills and smelting plants is regularly bid into the BM. This means that profit can be made both from the stand by compensation (the option price) and from active participation in the BM.

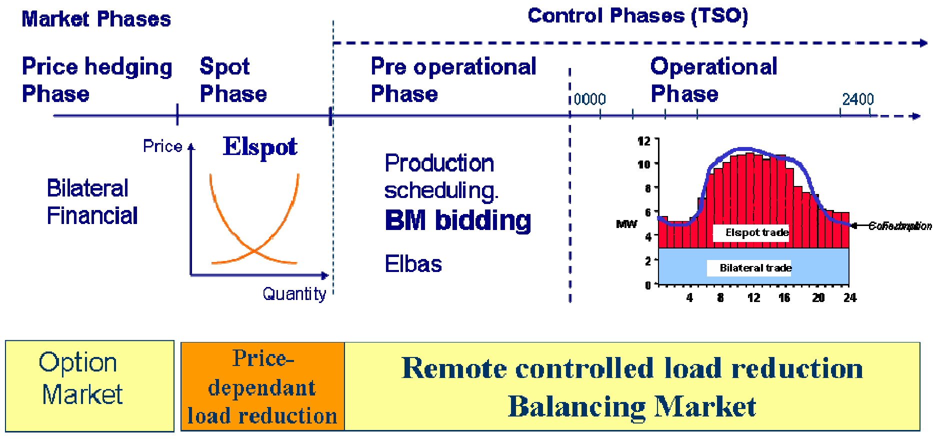


Figure 2 Demand response options in the market and control phases.

The two categories of demand response are illustrated in Figure 2 referred to the different phases in the transition from market to physical operation of the Norwegian system. The *market phases*

[2] In Norway called the Regulation Power Market

start with bilateral contracting and financial trading and end with the spot market settlement every day at noon. The *Control phases* start with the *pre operational phase* where production scheduling is carried out by each producer and the market players submit bids for the real time balancing market. The regulation objects are used for manually secondary control in the *operational phase* to keep frequency and time deviation within limits. The Reserves Option Market is defined as a part of the financial trading with direct impact on the offers to the Balancing Market, while the consumer spot market involvement is labelled as price dependant load reduction.

4 EXPECTED BENEFITS FROM AUTOMATIC DR TO SPOT PRICE

The most important socio economic benefit of hourly metering and RLC is the potential of load reduction in periods of shortage, which will reduce the need for investment in new production and/or transmission capacity. The exact value of the benefit is difficult to calculate because the price reduction achieved affects all the players in the market, and some actors, e.g. the producers, will lose money.

However, the example from the California crisis in June 2000 where the market prices rose to up to 10 times historical level, rolling blackouts were instituted, and bankruptcy of several institutions occurred, shows that the cost of shortage can be enormous. According to [5] only 300 MW, out of a total of 50 000 MW, load reduction for a few hours would have been sufficient to avoid the rolling blackouts.

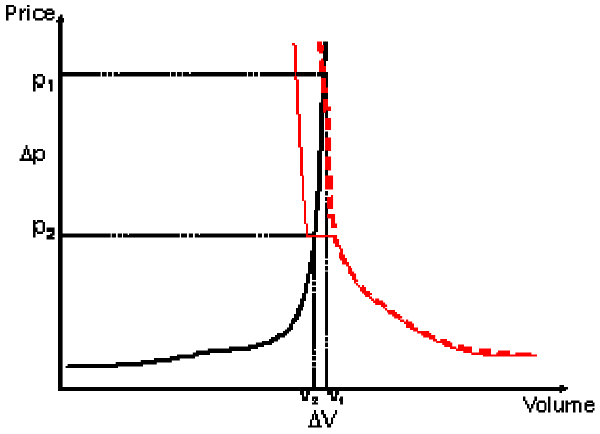


Figure 3 Price reduction in peak load due to Demand Response.

Figure 3 illustrates that only a small price dependant load reduction ΔV will result in a substantial drop in price Δp, and in some cases secures an acceptable price and an initial balance in the day ahead market.

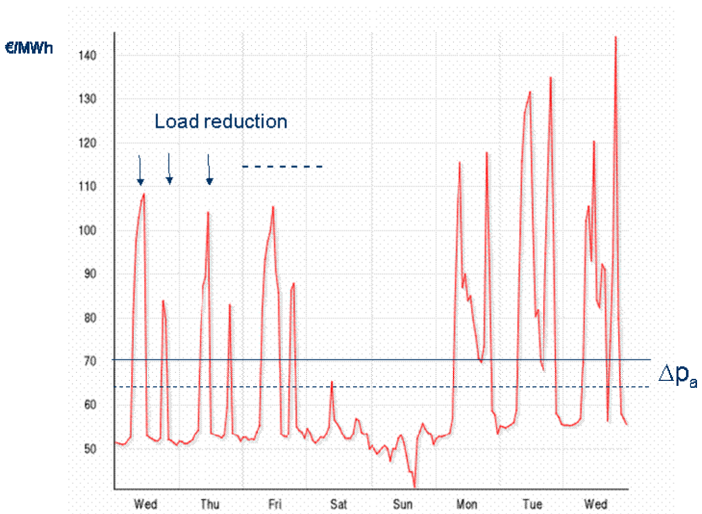


Figure 4 Impact of systematic load reduction in peak hours.

This can be further illustrated by looking at recent price spikes in the Nordic Market. Figure 4 shows the hourly prices for one week this winter for one of the Nord Pool price areas. Limited import capacity to the area was the main reason for the spikes. In this case adequate demand response in the peak hours would not only have reduced the high prices, but also the average price, p_a, over the one week period, as shown on the figure. This means that all customers would benefit from the reduced price, and the customers who are contributing by systematic load reduction, would have an extra benefit due to the reduced consumption in these hours.

In such bottleneck situations there is a possibility for market power abuse. A small portion of automatic price response from the demand side would mitigate this threat.

The reasoning above is valid for all load reduction in the peak hours. However, the benefit will be very much dependant of the volatility of the spot market for load shifting from one hour to the other each work day, as is the case for switching of water heaters. Analyses based on historical data from the Nordic power system [6] show that the socio economic benefit is limited in the present Nordic market. Still, there are good arguments for “training” the customers to activate load shifting regularly, and by that achieving a benefit in peak load periods that would not be in place otherwise.

The Automatic Demand Response (ADR) scheme that is shown in the demonstrator, will in large scale contribute to increased price elasticity in the day ahead and balancing markets. The following potential benefits for the involved actors can be achieved:

Customer: The flexible customers will improve their energy economy when consumption is reduced in periods with high prices.

Distribution System Operator (DSO): RLC technology can reduce bottleneck problems in the distribution system, and the DSO can benefit from reduced system losses by load reduction in the peak hours. Customer satisfaction can be increased, and RLC services for customers and/or suppliers can be commercialized in the future.

Power Supplier: The Supplier is in principle a separate body, without production, who is buying electricity from the organized markets (Nord Pool) and selling to the end users. The customers are free to change supplier, which stimulates a more efficient competition. Development of new and attractive contracts for electricity that include automatic load reduction when the prices are high, is therefore in the interest of the suppliers. There is also a potential for reduction of the volume risk in high price periods.

Technology manufactures/ vendors: On the technology side there is an opportunity in development of new commercial products with a large international market potential.

5 AUTOMATIC RLC REFERRED TO SPOT PRICE

5.1 Disconnection of low prioritized appliances

The *low prioritized appliances*, and not the total load, are defined as the *Demand Response Objects*, based on the assumption that there is a limit for what the customers are willing to pay for different uses of electricity.

Some of these appliances, like water heaters and other heating with storage, can be disconnected for a few hours without any discomfort or cost for the customer. These DR objects represent load shifting and have “0” as alternative price in the peak hours. Other appliances like ventilation, may have a certain value for the customer while industry production lines might have a higher value e.g. referred to alternative energy sources. It is up to the customer to define the price they are willing to pay for supplying the different appliances. Figure 5 illustrates examples of low prioritized appliances and price levels.

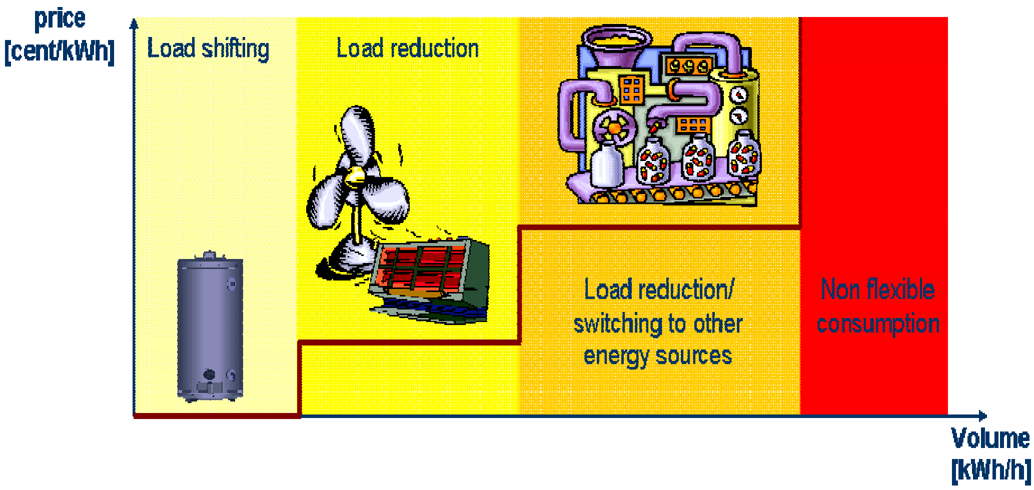


Figure 5 “Low prioritized” appliances.

Disconnection of water heaters are chosen for Demo I. The example below gives an indication of the potential volume of load reduction by this DR action in the morning hours on working days.

Example:
Figure 6 shows the result of disconnection of approximately 1500 water heaters during the different morning hours. Note that only the average consumption within each hour is metered (kWh/h), which means that the instantaneous effect of out and in switching is not detected. The highest load reduction is registered in hour 8-9, which coincides with the Nordic peak hour. The installed capacity of the water heaters is 2 kW and the measurements show that ~0,5 kWh/h is the expected average load reduction in the morning hours, which indicates an average coincidence factor of 20-25 %. In addition to this, load reduction in a load centre will give a reduction of network losses of ~20 % compared to a correspondingly increase in production in a remote power station. This means that the water heater potential can be estimated to 0,6 kWh/h in the peak

hours. For Norway this indicates that a total of 600 MWh/h load reduction from water heaters could be achieved, provided contribution from half of the 2 million Norwegian households [7].

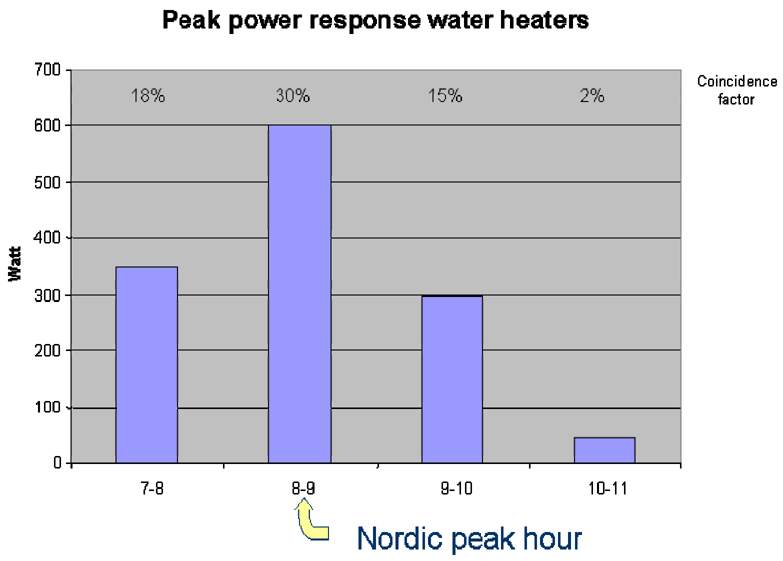


Figure 6 Average water heater load in the morning hours.

5.2 The Spot Price Criterion

The main idea behind offering RLC referred to spot price is the assumption that most customers are not interested in paying attention to the variations in the spot price from day to day. The network company can offer these customers automatic load reduction via the AMR system or in combination with a separate RLC system. The spot price is known 12-36 hours before the hour of operation, which makes it possible to program the RLC in advance. For effective use, a web based interface is recommended.

The Spot Price Criterion is illustrated in Figure 7. The figure shows the spot prices for a winter day, where the prices in the morning and afternoon hours were much higher than average spot price. The pink square dotted line is the hourly consumption for a household. This customer has a contract with the supplier that implies disconnection of selected appliances when spot price exceeds 7 cent/hour. In this example the spot price turns out to be above this level for 9 hours of the day, which means that the selected appliances are automatically disconnected at 08:00, reconnected at 13:00, disconnected at 17:00 and finally reconnected at 21:00 in the evening. The blue diamond dotted curve indicates the response from the automatic RLC.

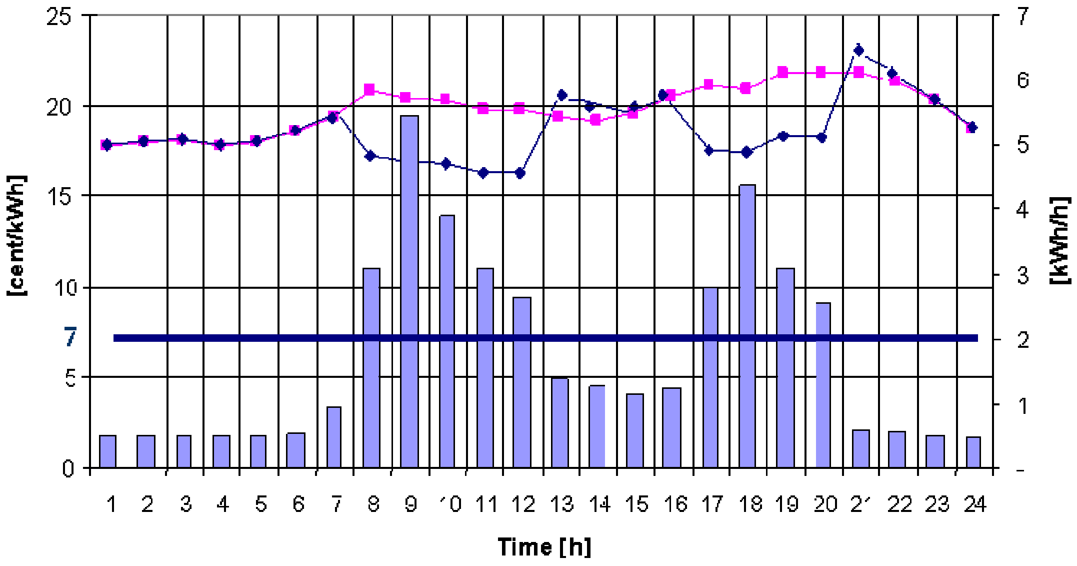


Figure 7 Automatic load reduction referred to spot price level.

The principle for Automatic Demand Response (ADR) to spot price is illustrated in Figure 8. The prices from the day ahead market, Nord Pool Elspot, is collected from the Internet or the Nord Pool FTP server by the load control software. The prices are compared with the contracted spot price levels for RLC of the selected appliances within the defined time frame (e.g. 07:00-11:00 and 17:00-20:00). Disconnection and reconnection of loads are scheduled for the next day and RLC of e.g. water heaters (WH) are performed automatically without involvement of the customers.

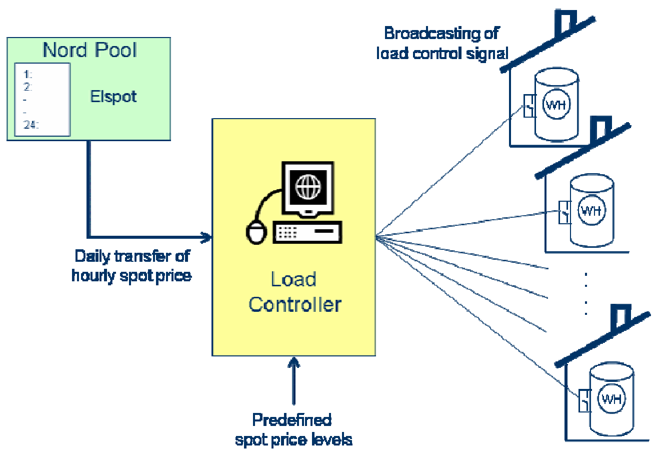


Figure 8 Load reduction based on the spot price criterion.

5.3 Customer contracts and Elspot bidding

One of the main advantages of ADR to day ahead prices (Elspot) as described in this report is that expected volume of the load reduction at a certain price is known and thereby can be bid into the market. Load reductions in the operational phase might result in a high unbalance cost if the load reduction is *not* included in the spot market bids.

Both the power supplier and the network operator (DSO) are involved with the customers when offering power contracts, network tariffs and RLC. A general arrangement concerning contracts and Elspot bidding can be as follows (see Figure 9):

- The power suppliers enter into a contract concerning volume and price for reducible load, with customers that have hourly metering and RLC. For practical reasons it is expected that only a few spot price levels for disconnection would be offered, both to limit the contract variety for the power supplier and to ease the alternatives for the customer.
- The power supplier and the network operator have to make an agreement concerning the RLC.
- The power supplier includes the price/volume information from the RLC contract in the Elspot bids.
- The network operator receives information of the spot prices the day ahead and plans and performs the load disconnections.

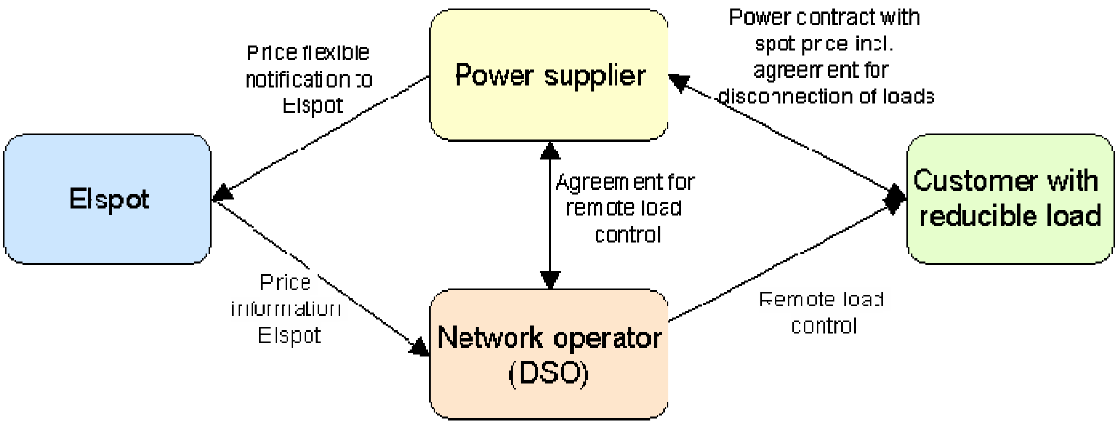


Figure 9 Contractual and technical arrangements.

As an example, the bid curve for a supplier with contracted automatic load reduction when the spot price exceeds the predefined limits 400 NOK/MWh[3], 600 NOK/MWh and 900 NOK/MWh is illustrated in Figure 10. The reducible volume on each price level is known from the agreement.

[3] 1 NOK = 0,13 €

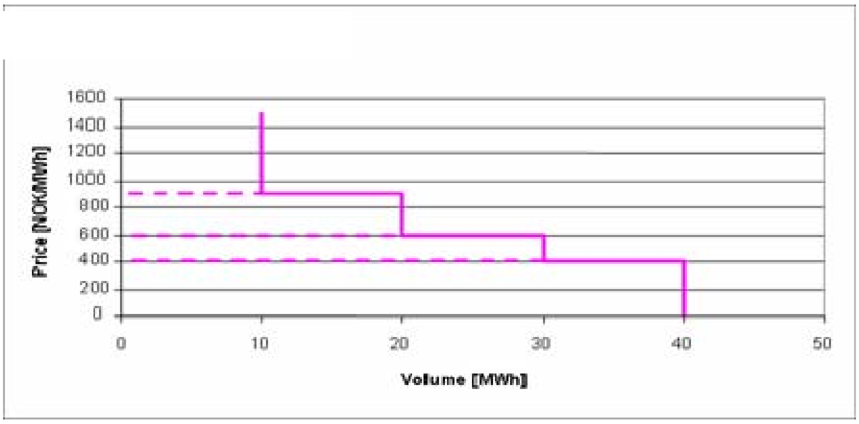


Figure 10 Example bid curve for the accumulated contracted load reduction.

6 TECHNICAL SOLUTION AND RESULTS DEMO I

6.1 Test site

The test was performed at residential customers living in a group of single houses under the distribution feeder called "Meiersvingen"[4]. All the houses were equipped with an Ebox RLC unit attached to the water heater socket. The Ebox was controlled via radio (see chapter 6.3). All the houses were hourly metered via AMR. See Figure 11.

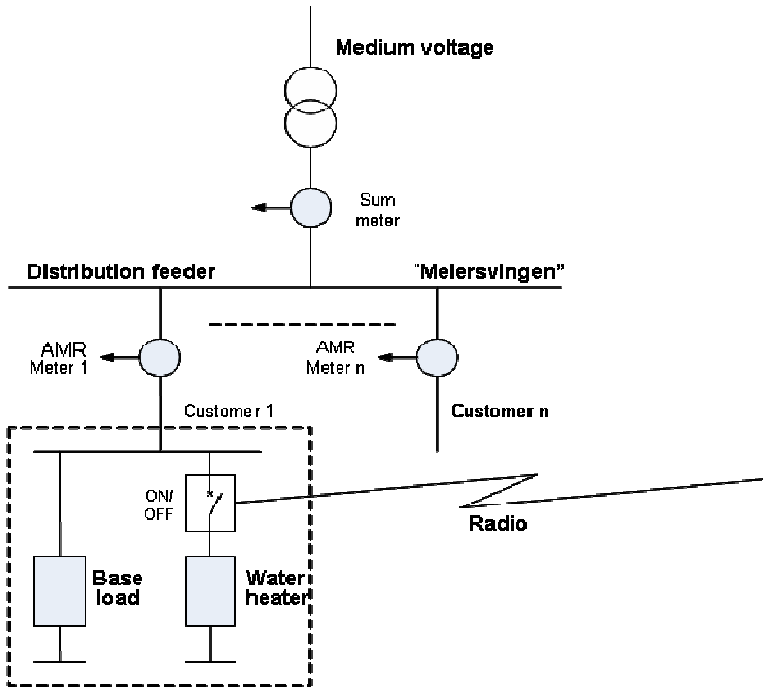


Figure 11 "Meiersvingen" test site.

6.2 Main principles for load control and documentation

The following principles are basic for the demonstrator:

- The disconnect able load is switched off at the start of the scheduled period and reconnected at the end of the period.
- The settlement and invoicing is based on hourly metered values (kWh/h), which means that the customer benefit is equivalent to the accumulated changes in the electricity cost per hour.
- The actual load reduction is documented by comparison between the real meter values for the period and a reference curve.

[4]"Meiersvingen" is a branch of the distribution system operated by the DSO Skagerak Nett.

6.3 Interplay between IT systems

The demonstrator is based on the functionality of two existing software solution:

- The LeKey for remote load control from APAS (previously Elink AS)
- The Metered Data Management System (MDMS) for documentation and settlement from Powel ASA

Figure 12 presents an overview of the interplay between the two systems. LeKey receives the Elspot prices from Nord Pool (Power Exchange) and performs the load control referred to the pre defined parameters and restrictions contracted with the individual customer or customer groups.

The MDMS collects the meter values from the metering system, in this case the AMR system, and processes the data for settlement and billing for all the customers. The customers can be grouped with reference to the suppliers involved, and the customers having load control contracts are treated specially for documentation of the load response.

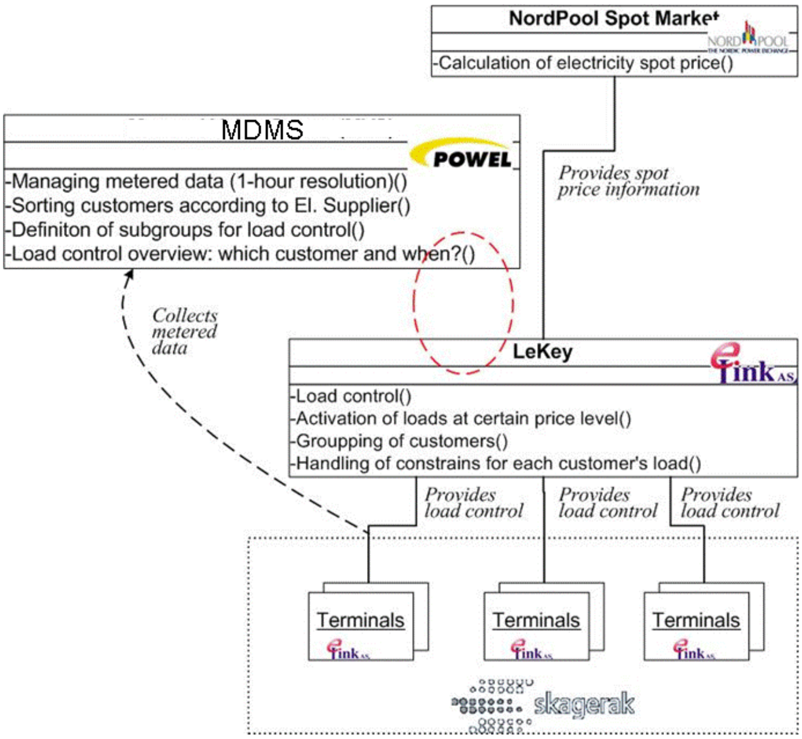


Figure 12 Overview of technical solution.

Definition of customer groups:

- Load Management Groups are generated and configured for RLC in LeKey.
- The Group is identified by an EAN[5] number for the individual customer.
- All the customers with AMR are registered in the MDMS as separate import references with the EAN as the identification together with relevant customer information.
- The EAN is also the basis for automatic collection of hourly metered values from the MDMS.

Profile estimation:

- The MDMS calculates the load profile of the customer group *without load control* (based on historical data). The profile can either be stored in the database or exported for settlement purposes.
- The load profile *with load control* is stored in the data base.
- The MDMS calculates the difference between the profile with and without load control. The difference is stored as a separate profile for documentation of the load control impact.
- Time series of the Elspot price is automatically updated in the MDMS and the net cost is calculated by multiplication with the hourly metered values.
- Different reports can be generated from the MDMS.

Data exchange between LeKey and MDMS

- LeKey updates the MDMS with the EAN identification of the customers with load control.
- Broadcasted signal for load control from LeKey is complemented by a transmission of a status indication for each customer to the MDMS.

In this version of the demonstrator all the parameters are set manually.

Data exchange from MDMS to external billing systems:

The settlement and documentation is in this version of the demonstrator performed by the MDMS.

[5] EAN= European Article Numbering

6.4 Remote Load Control via "LeKey"

LeKey is a generic system that can be used for load control with different technologies, e.g. separate RLC systems and different AMR systems. In this particular demonstrator radio based remote load control of in total 40 Ebox terminals was established to perform disconnection and reconnection of residential household water heaters referred to spot price level. (Other Lekey applications, such as Regulation Power control, are described in Appendix I.)

6.4.1 Infrastructure

Figure 13 shows the main elements in the load control scheme used in the demonstrator. LeKey collects Elspot price information from the Nord Pool file server and processes a list of loads to be disconnected (address and time). The signal for disconnection is distributed at the start of the hour (defined by the list) to the load control infrastructure, which in this demo includes three radio transmitters and several E-box terminals. A GPRS[6] interface is used between the LeKey software and the load control system.

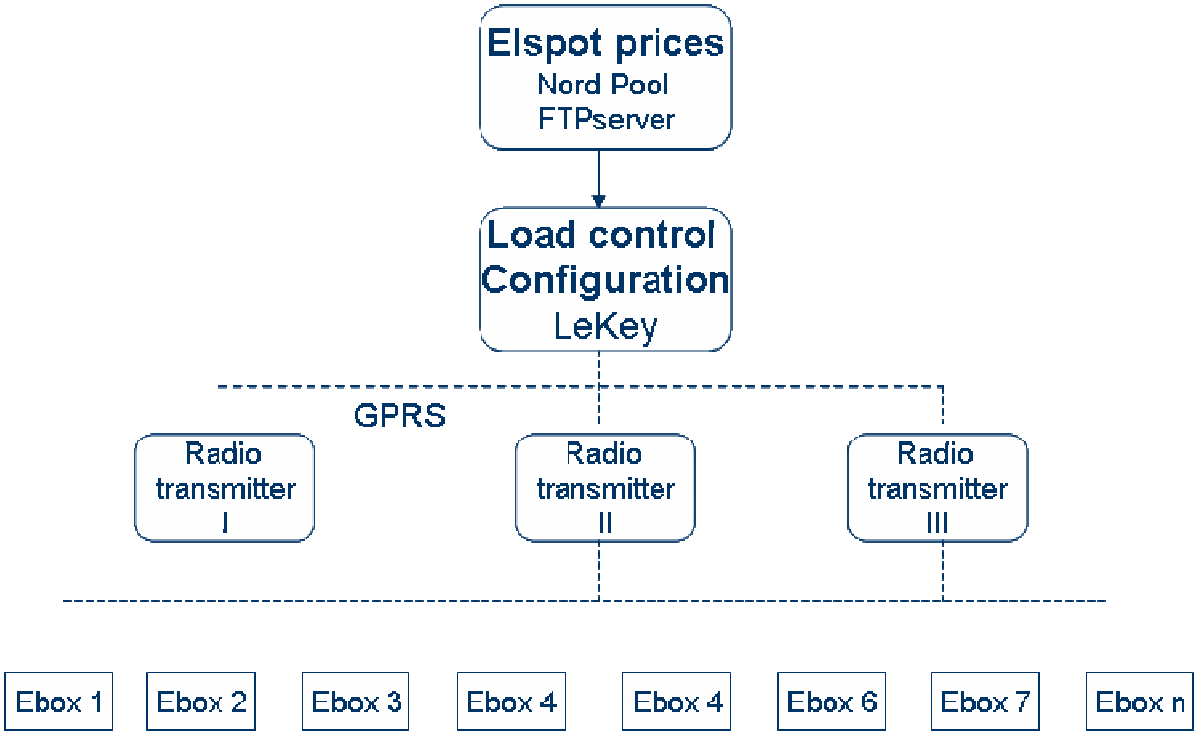


Figure 13 LeKey control scheme.

The system is "self driven" in the operational state, meaning that power control is done according to the applied configuration. One of the important modifications done to Ebox before this test is that Ebox has a default ON state when Ebox is booting up after a power shut down in the area. This is a "fail-to-safe" functionality so that the water heaters cannot accidentally permanently be in OFF state.

[6] GPRS=General Packet Radio Service

6.4.2 Ebox functionalities

As illustrated in Figure 14 the Ebox is a small unit that is plugged into a power outlet. The residential household water heaters in the test is powered directly via the Ebox. The customer can verify that the Ebox is operational when the Ebox is displaying correct time, and the OK led is on.

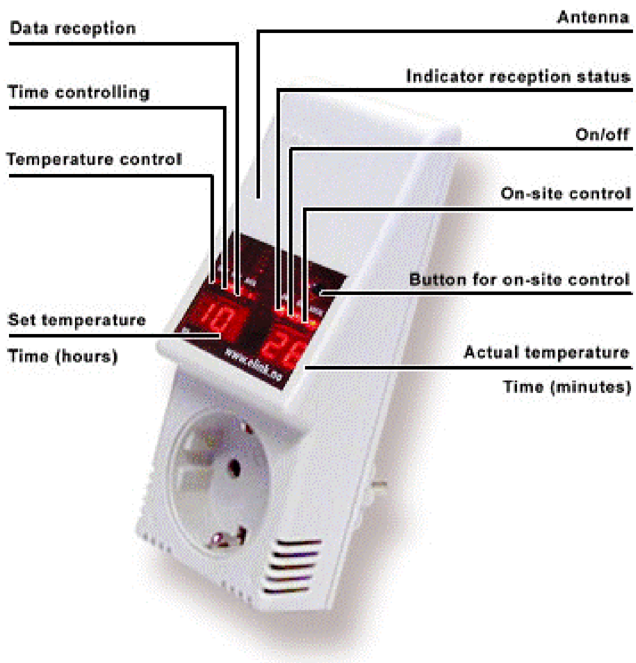


Figure 14 Ebox functionalities.

The Ebox has two addresses, one permanent individual address used for configuration and individual control profiles. The other address is a configurable broadcasting address that can be shared by an unlimited amount of Eboxes. The Ebox can be configured individually for local energy savings and control. However this is not an issue for residential household water heaters and has not been applied in this test.

The broadcast address has been applied to the Eboxes, which can be organized in a hierarchic manner with different broadcast addresses. Power control has been executed with broadcast signals. The Ebox receives continuously synchronized calendar information from the radio network.

The Lekey Ebox functionality is integrated so that different Ebox groups can be made, and then broadcasting addresses are sent to all Eboxes in that group. An Ebox group is then defined as a load in LeKey, and can be grouped together with any other load group in the system for remote load control.

6.4.3 Load group definition

Different loads can be grouped together as dynamic load groups in LeKey. One load can be member of several different load groups at the same time. The purpose of load groups is the ability to easily do simultaneous RLC of different loads and load groups. In the test there was established a load group named «Ebox spot».

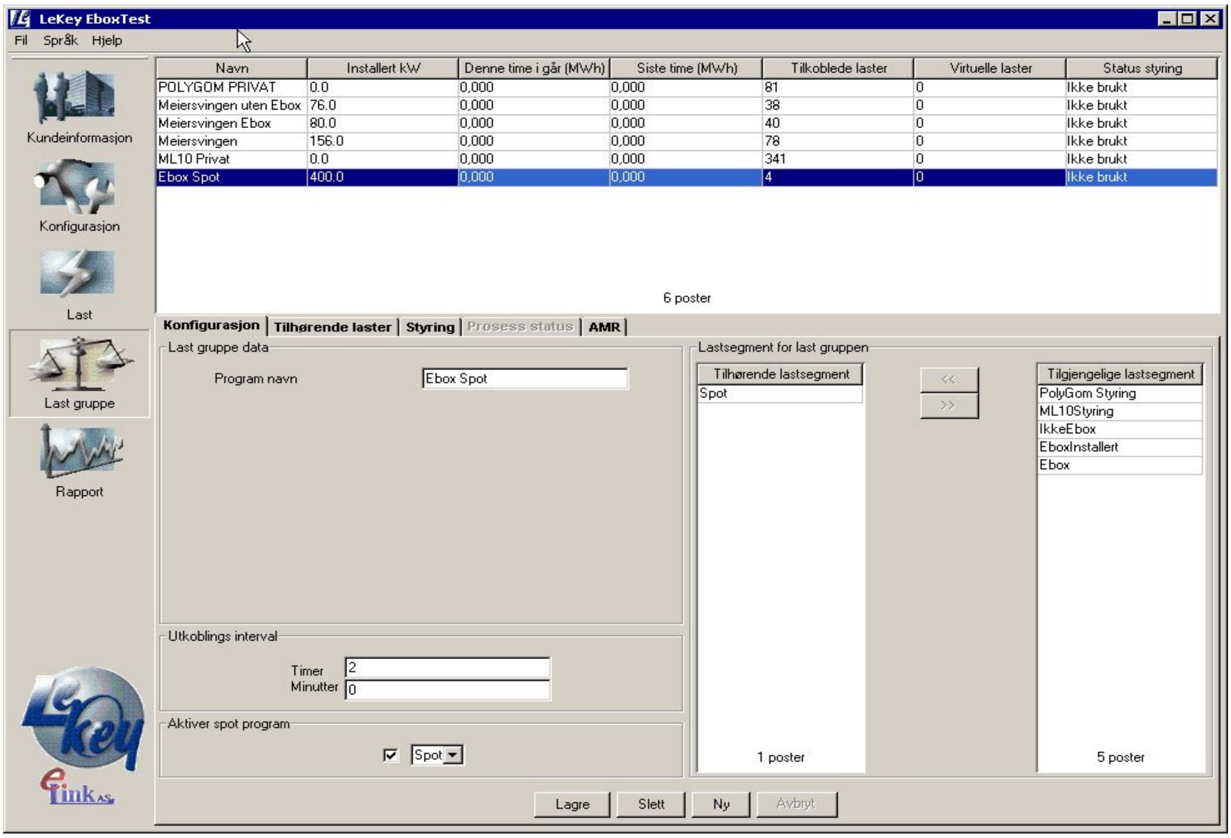


Figure 15 LeKey Screen shot Load group definition.

The screen shot (Norwegian version) shows a list of vital data about the load group, explained in Table 1.

Table 1 Load group definition.

Name	***Functionality***
Name	Name of the load group.
Spot Program	A list of all Spot Programs defined. By choosing a Spot Program the load group is connected to the spot service, and RLC will be executed automatically based on the spot service data, defined in the «spot program».
Connected load segments	Here you can group loads by functionality. By choosing the segment called «Spot», all loads with that segment will join the load group.
Available load segments	Lists all available load segments defined in LeKey.
Connected loads	Shows all connected loads in that load group, listed with the most vital load data. In this case showing loads with the «Spot» load segment attached
Power off interval	Duration of disconnection

6.4.4 RLC scheme referred the Elspot price level

As many spot programs as wished can be defined in the LeKey software. A spot program is defined by a set of criteria, that are used in an algorithm calculating if RLC is to be done or not. At 3 o'clock PM every day LeKey compares the spot program criteria with the spot prices for the day ahead market. The result is that the connected load group is scheduled for RLC if the spot program price limit is exceeded within certain time intervals. The responsible LeKey operators will automatically receive an email message reporting the planned power controls. The power controls will be executed if no changes are made manually. A detailed description of the spot program is given in Table 2.

Table 2 Spot program.

Criteria	***Comments***
Name	The name of the spot program. All changes made to the spot program will be applied to the connected load groups.
Price limit (NOK/MWh)	"Limit" defines which spot prices to take into consideration for a possible power control. This is illustrated by the following examples: 1) If price limit is above the maximum spot price the next day, no RLC will be scheduled. 2) If price limit is set to zero, LeKey will schedule RLC in the time intervals where spot price is highest. 3) If price limit is set between the highest and the lowest spot price, RLC will be scheduled at the hours of highest spot prices, and where spot price is exceeding price limit.
Start time period 1	Earliest start of power out in period 1.
Stop time period 1	Latest stop of power out in period 1.
Start time period 2	Earliest start of power out in period 2.
Stop time period 2	Latest stop of power out in period 2.
Max power out interval	Defining for how long a load can be OFF.
Max no power in period	Max power out pr day.
Elspot area	The spot program will be referring to the actual price area.

6.5 Powel MDMS – Settlement report and documentation

Powel MDMS is a software solution used for management of AMR data from end use customers. The system is a market leader in the Nordic countries and represents a solution for utilities – small and large – in their effort related to manage the increasing amount of metered data. Powel MDMS is flexible and scalable in a way that makes it easy to fit to work processes in both operation as well as for rolling out AMR solutions that includes time series with different resolutions and time stamps. Powel MDMS is based on an Oracle platform and includes among others the following functionalities:

- Data collection of metered data independent of meter vendor.
- Control and correction of collected metered values.
- Historical storage and event log for all data.
- Time series calculator for reports and analyses.
- Flexible report tool for documentation of demand response actions.
- Interface for presenting web-reports of time series and key figures.
- Asset manager for all kind of metering components (meter, transformer, terminal etc.) and work order system for changes of installation.

All these functions make Powel MDMS to be a software system prepared for large amounts of data and management of metered data in a way that makes it well fitted for adding value with reports and customer services.

Powel MDMS is integrated with applications regarding energy trade and generation planning.

Figure 16 shows the role of Powel MDMS as a part of the value chain from meter to cash in utilities. More info about the tool is found in Appendix II.

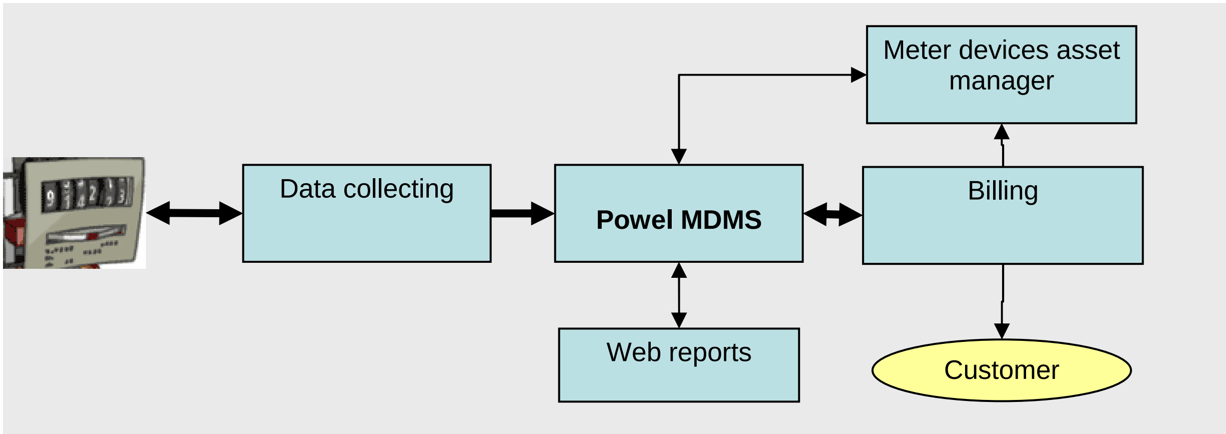


Figure 16 Powel MDMS in the value chain from meter to cash.

Due to the fact that Powel MDMS includes a general and powerful time series calculator, the system is well fitted for establishing reports and accounts for customers with load management and demand response actions. To perform calculations like this, it is established specific calculation expressions linked to the time series/customers that shall be included in the calculations. Powel MDMS takes care of periods that are valid for the different meters/time series. It also secures that the quality of the data is ok and trace all information and the storage of the results as well as it exports the results to the billing system or another accounting systems.

The screen shot in Figure 17 presents functions used for establishing and editing expressions for calculations. As shown, it includes name of time series, mathematical operators and statistical functions including a separate area showing the entire expression to be executed. The calculation presented gives a comparison between the load profile from metering with a reference profile, in this case a day the same week without load control.

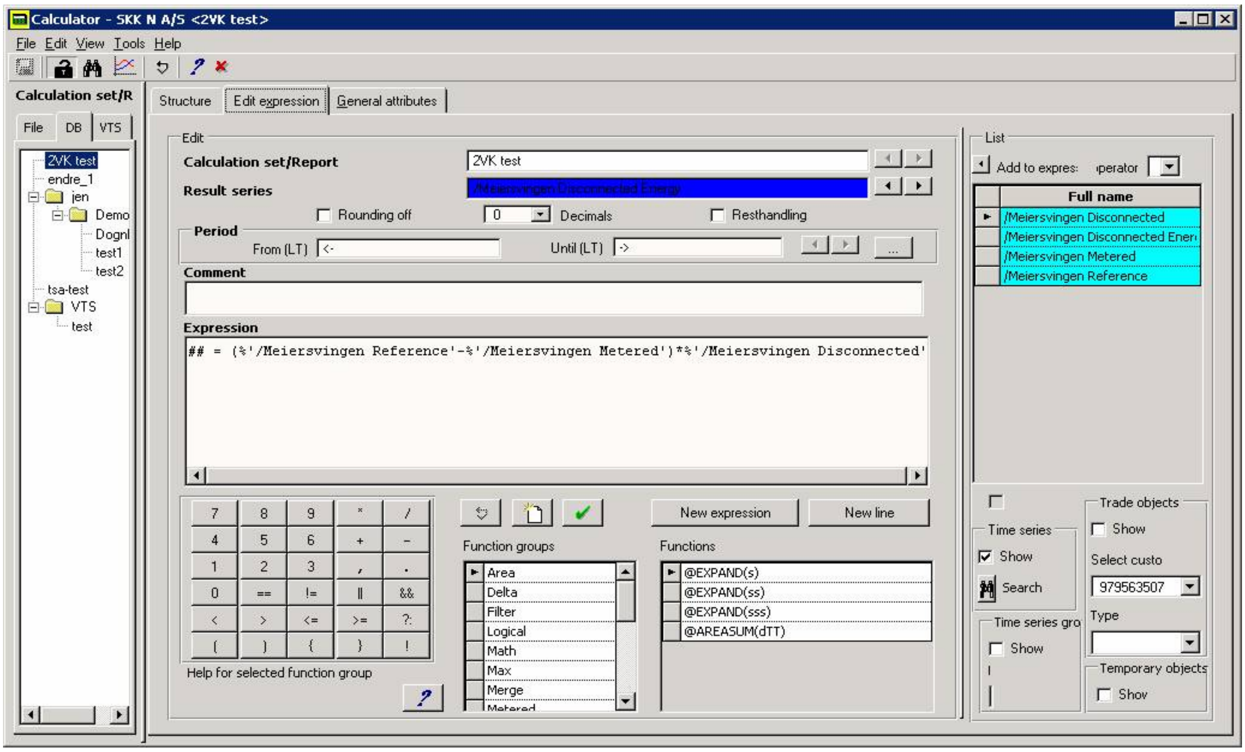


Figure 17 Screen shot in Powel MDMS for establishing calculations and reports regarding demand response. Example from load group “Meiersvingen”.

In the left side of the figure it is shown in a three structure name and content of the reports that are linked to this example of load management – here named as “2VK test. Name/Code shows the time series that are included to establish the report, and in this case the explicit calculation of the time series “Meiersvingen metered” and “Meiersvingen reference” are applied. It is a challenge to develop and implement methods for estimation that keeps an acceptable level of precision. However Powel MDMS holds a range of functions (“Function groups”) and formulas (“Functions”) that gives the operator the possibility to establish methods precise enough.

The reference time series are subtracted hour by hour for the metered values the present week. The resulting time series is called ”Meiersvingen Disconnected Energy” and represents the value of disconnected load hour by hour. The time series for disconnected load is multiplied with actual spot-price every hour. Powel MDMS has functions making it possible to do calculations in specified time masks (specified hours during the day), which means that the calculation is only valid for the hours when disconnection is active.

6.6 Documentation from test (week 24/05)

Several tests were carried out over a period of 2 months. Results from week no. 24/05 are chosen to illustrate the registered response on the load curves. In this week LeKey activated load control Tuesday 14, Wednesday 15 and Thursday 16. The load curve for Friday 17, without intervention, is used as reference.

6.6.1 Selection of hours for RLC activation

"The two highest priced hours between 07:00 - 11:00 and between 16:00 - 20:00" was defined as criterion for disconnection of water heaters in this test. The minimum spot price level was set to 100 NOK/MWh. The time for disconnection and reconnection is defined by the hourly prices on Nord Pool Elspot as shown in Table 3 and Table 4.

Table 3 Selection of hours for load control referred to Elspot prices [NOK/MWh].

Date \ hour	00-08	07-08	08-09	09-10	10-11	11-16	16-17	17-18	18-19	19-20	20-24
15.06.2005		237,56	244,77	245,76	245,7		232,82	230,87	228,87	228,34	
16.06.2005		225,18	232,03	230,95	232,81		220,33	217,66	215,52	211,01	

Table 4 Timing of load control.

Date	Disconnection	Reconnection
15.06.2005	09:00	11:00
15.06.2005	16:00	18:00
16.06.2005	08:00	09:00
16.06.2005	10:00	11:00
16.06.2005	16:00	18:00

6.6.2 Load curve impact

Figure 18 and Figure 19 show the accumulated load curves for "Meiersvingen" for the June 15 and 16 respectively. The curves are "normalized", which means that they are relative to the average meter value for each period (in this case 24 hours). The load curve for June 17 is used as reference in both cases.

The curves show significant response to the activated control in the morning hours. In the afternoon it is more difficult to register the response. The explanation for this difference is probably related to the activity in the households. Several “disturbing” activities like cooking etc. are likely to take place in the afternoon while low activity is normal in the morning hours on working days.

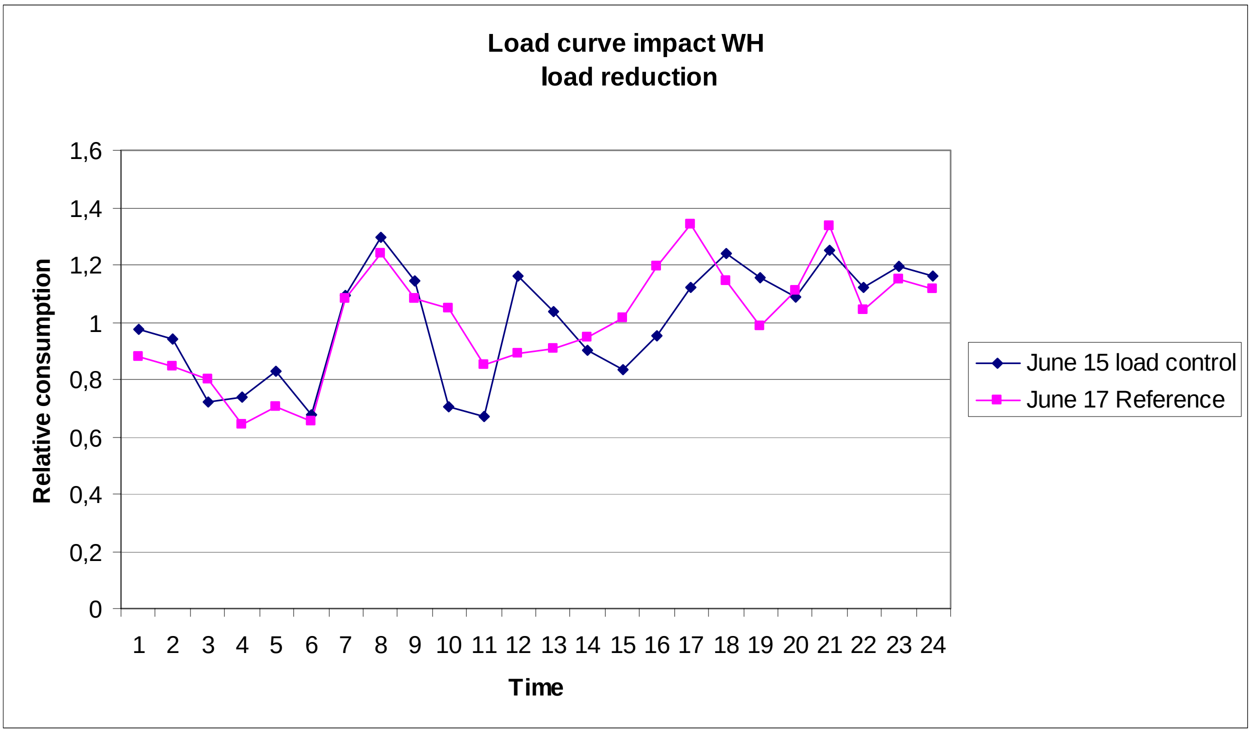


Figure 18 Response curve June 15.

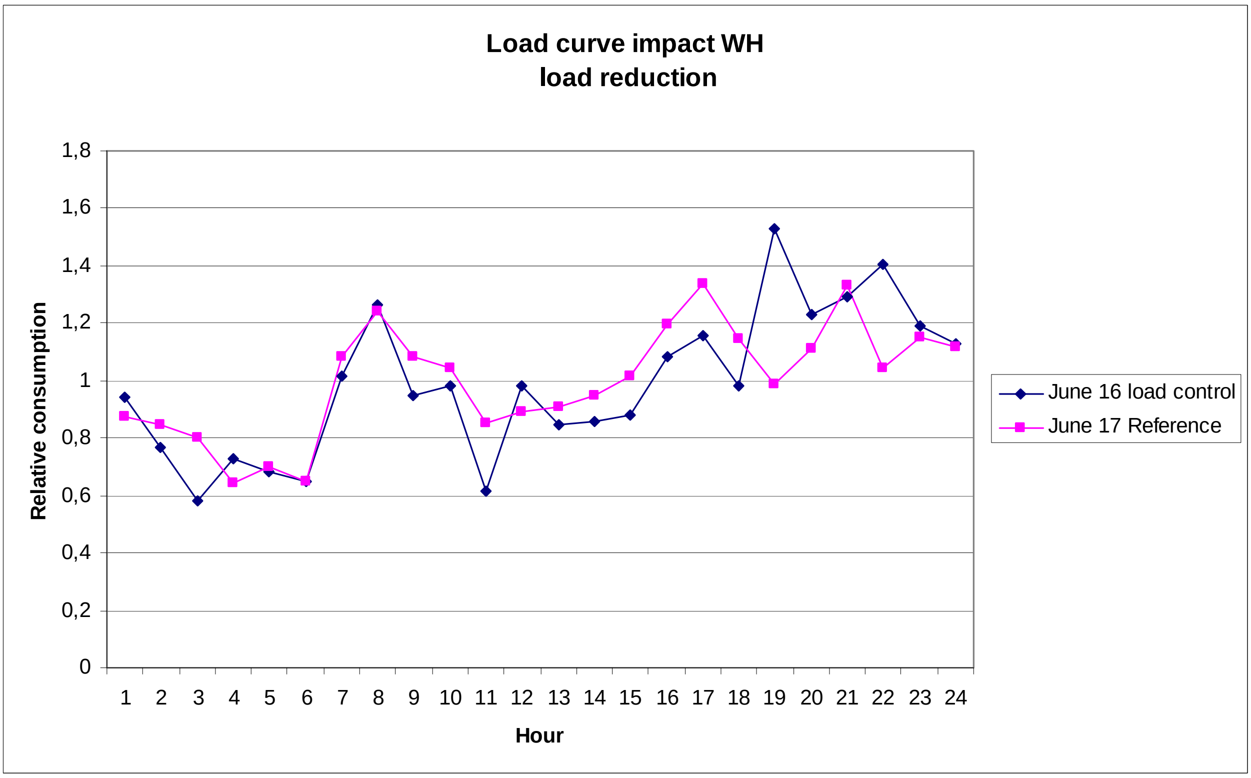
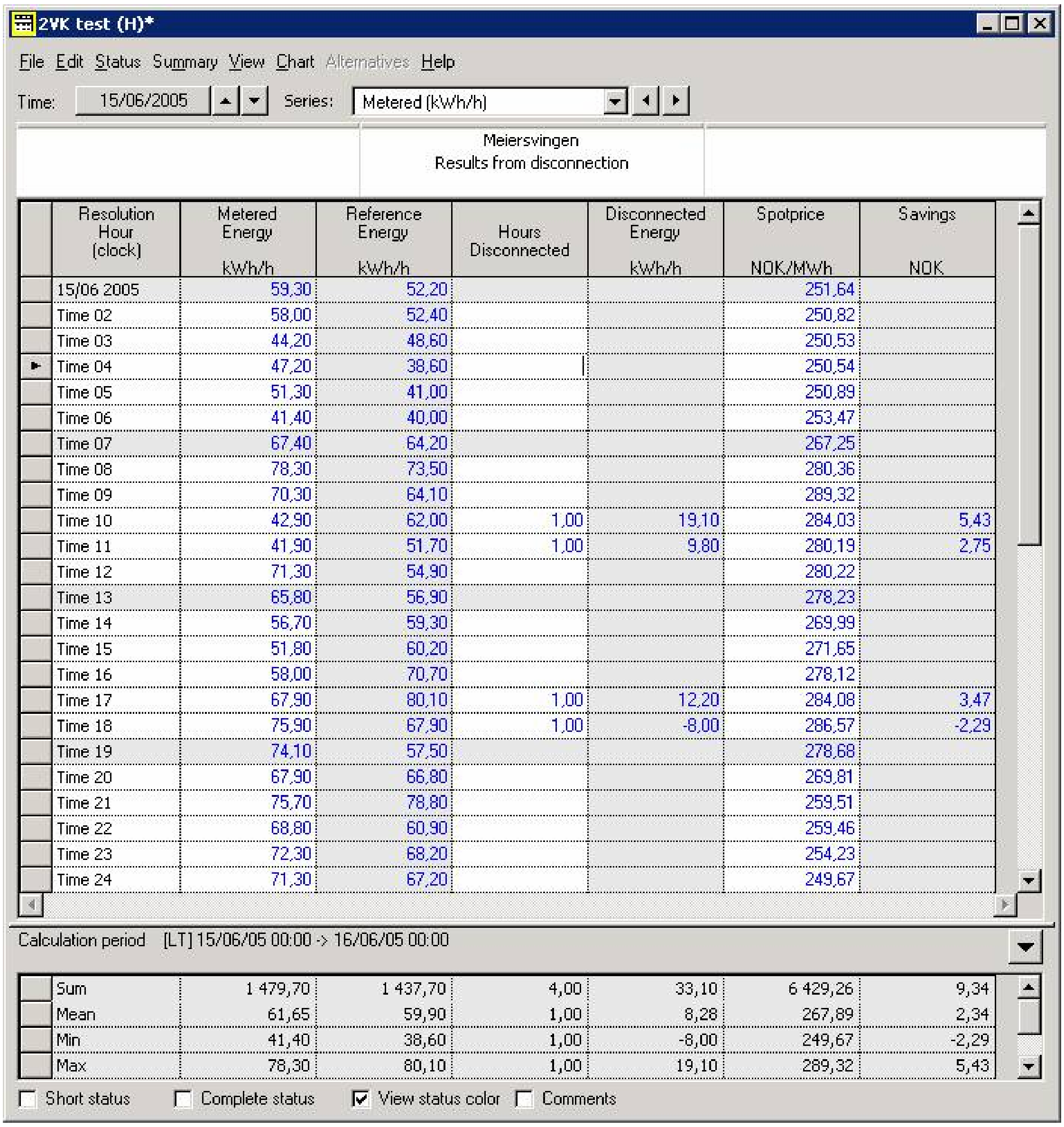


Figure 19 Response curve June 16.

6.6.3 Settlement report

For the case ”Meiersvingen” time series are imported to Powel MDMS for further processing and calculations. To present metered data and the resulting time series showing the impact (demand response) of the disconnected load, expressions are established in the calculator module of Powel MDMS. The basic time series for the reports are stored in a way that makes it is possible for the operator/user to specify the period for every time the report is activated.

The screen shot in Figure 20 presents metered load profile (June 15), metered load profile reference (June 17) and disconnected load. In addition the value of estimated disconnected energy is presented. For visualizing this situation the column “Meiersvingen Disconnected Energy” shows values that in a way represent disconnected load hourly. The figure also presents a table summarizing the consumption during the period including total demand response.


2VK test (H)*

File Edit Status Summary View Chart Alternatives Help

Time: 15/06/2005 Series: Metered (kWh/h)

Meiersvingen
Results from disconnection

Resolution Hour (clock)	Metered Energy kWh/h	Reference Energy kWh/h	Hours Disconnected	Disconnected Energy kWh/h	Spotprice NOK/MWh	Savings NOK
15/06 2005	59,30	52,20			251,64	
Time 02	58,00	52,40			250,82	
Time 03	44,20	48,60			250,53	
Time 04	47,20	38,60			250,54	
Time 05	51,30	41,00			250,89	
Time 06	41,40	40,00			253,47	
Time 07	67,40	64,20			267,25	
Time 08	78,30	73,50			280,36	
Time 09	70,30	64,10			289,32	
Time 10	42,90	62,00	1,00	19,10	284,03	5,43
Time 11	41,90	51,70	1,00	9,80	280,19	2,75
Time 12	71,30	54,90			280,22	
Time 13	65,80	56,90			278,23	
Time 14	56,70	59,30			269,99	
Time 15	51,80	60,20			271,65	
Time 16	58,00	70,70			278,12	
Time 17	67,90	80,10	1,00	12,20	284,08	3,47
Time 18	75,90	67,90	1,00	-8,00	286,57	-2,29
Time 19	74,10	57,50			278,68	
Time 20	67,90	66,80			269,81	
Time 21	75,70	78,80			259,51	
Time 22	68,80	60,90			259,46	
Time 23	72,30	68,20			254,23	
Time 24	71,30	67,20			249,67	

Calculation period [LT] 15/06/05 00:00 -> 16/06/05 00:00

Sum	1 479,70	1 437,70	4,00	33,10	6 429,26	9,34
Mean	61,65	59,90	1,00	8,28	267,89	2,34
Min	41,40	38,60	1,00	-8,00	249,67	-2,29
Max	78,30	80,10	1,00	19,10	289,32	5,43

Short status / Complete status / View status color / Comments

Figure 20 Report showing metered disconnected load, load in reference period and calculated demand response for the day 15.06.2005.

The results are presented graphically in Figure 21. In addition the figure shows a curve that presents for which periods (09-11 and 16-18) the load is disconnected.

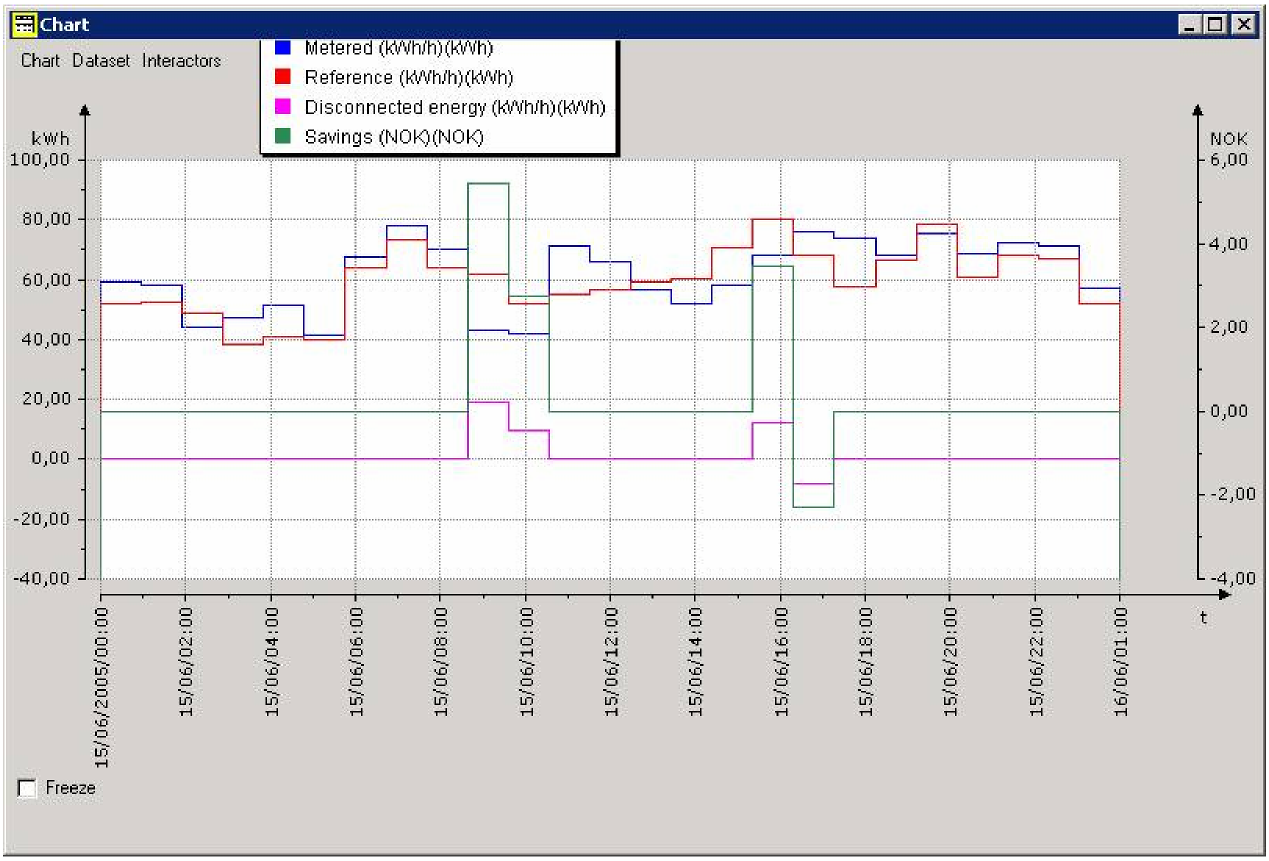


Figure 21 Presentation of calculated reports as curves.

It is possible to store all time series, either metered or calculated, for further analyses or export to the accounting systems. Powel MDMS may as well be used for establishing the economic settlement that is the result of the demand response. Most efficient to do this is to automatically import and store the price (hourly resolution) as a time series. Next step is then to multiply the price with calculated demand response (hourly resolution) and then stored as a resulting time series. This resulting time series will then be exported to the system responsible for the final billing for this DR product.

7 DISCUSSION – FURTHER WORK

This report documents a well functioning scheme for Automatic Demand Response referred to spot price level. Software and technology from two different vendors, APAS and Powel ASA, have been put together to demonstrate automatic remote load control of residential water heaters and efficient documentation of demand response and cost savings.

The tests were carried out in a period of two months where the Elspot prices were low and stable caused by a mild winter and well filled hydro reservoirs. Because of this the cost savings for the customers have been minimal. However, in the test period there were no reports of complaints from the customers, telling that 2 hours power disconnection of household water heaters has no disadvantage to the households. This means that this scheme should be used also in low priced periods, and by that establishing a load pattern that will have a significant impact in peak load periods.

Of course, disconnection of water heaters for a few hours morning and afternoon on working days can be done by using simpler means than the scheme presented in this report, e.g. with time relays. However, Demo I shows that load reduction referred to spot price level can be done in a smooth way, and the experiences from the demonstrator will now be used in a test case involving smaller industry and commercial end users. Selected low prioritized appliances that have an alternative price will be the demand response objects in this next test case, where the Supplier involved will offer the customers a contract involving price flexible bidding on Nord Pool Elspot.

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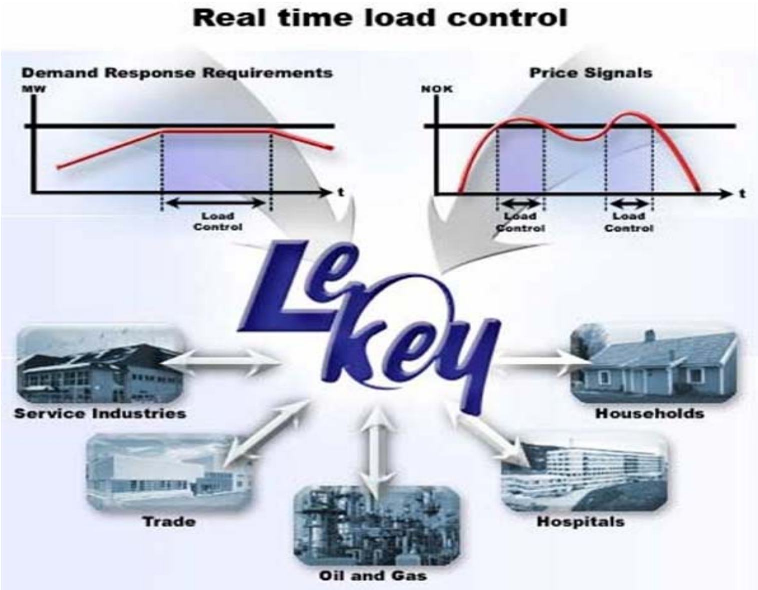
APPENDIX I: LEKEY



In general
LeKey is a leading system in the market of load management and power flexibility. LeKey can be used for:

- Load management – on- and off of energy loads, i.e. boilers.
- Reports of used/not used power in Reserves Options Market (ROM)
- Load management within price elastic spot notification
- Warning/information to customers of Load management, prices, and more.
- True power measurement and reports of loads and groups of loads.

Important features of LeKey

- Management of energy loads with use of GPRS/SMS terminals and third parties front-end terminals. Planned or real time load management.
- Warnings/information via SMS, email, fax or automated voice
- AMR (automatic meter reading) from terminal, direct or via third parties database
- Real time power measurement via GPRS terminals and third parties front-end terminals.
- NordPool spot prices can be used for automatic price based load management, with reports generated with energy consumption and prices.

Modules
LeKey is a rich featured system satisfying different needs within load management. LeKey has the following modules:

- Customer and contacts
- Configuration - Terminals, contracts regulating load management, load segments, and more.
- Load - Configuration, management, AMR
- Load groups - Configuration, management, AMR.
- Reports/graphs – Consumption, prices, management, warning, and more.

Terminals
LeKey supports the following terminal types:

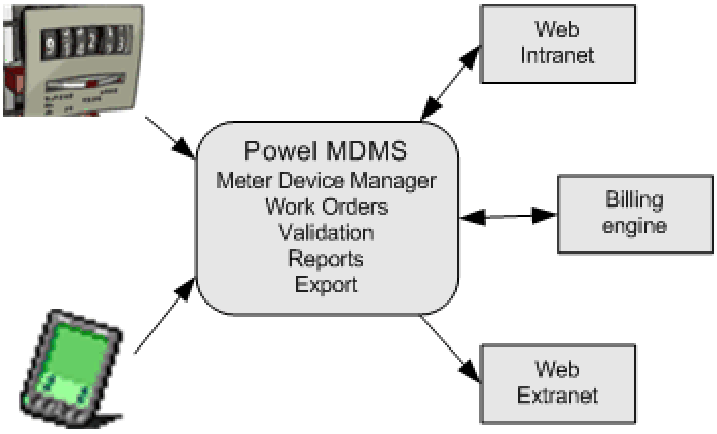
- Policom 6xx og 7xx
- Enermet D100, ML10, CentraPuls
- ETM 9600
- Comsel CIOS

Deployment
It is easy to get started with LeKey. Many customers use the Internet based LeKey ASP. It is also possible to install LeKey server locally in your own network, which enables integration with local systems, as MVDB, CIS (Meter Value Data Base and Customer Information System) and terminal front-ends.

LeKey is divided into an application server and a client. The application server communicates with terminals, front ends, and other internal or external systems. The client is used to edit, configure and present data, and to initiate or plan load management. When managing loads the application server is communicating directly with the terminals via GPRS, or via front ends from the terminal vendor. LeKey is based on the J2EE platform on the server side, and J2SE platform on the client, both platforms delivered by Sun Microsystems. LeKey is therefore scalable and standardized to meet future development needs within load management.

APPENDIX II: MDMS – THE POWEL SOLUTION

As a market leader in software solutions for utilities in Nordic power market, Powel offers to put its considerable technical expertise, market knowledge, and operational skill-base at the disposal of its utility customers. ***Powel MDMS*** validates, manages, stores, analysis, reports and exchanges the input data. The system interacts with the billing system in a way that secures a seamless chain from meter to cash.



Powel MDMS reads data on a wide variety of formats and EDI-messages. It also applies API-technology and web services to interface with billing systems and customers directly. It includes file formats and protocols to collect metered data from front end systems and hand held units.

Powel MDMS supports data collection for both interval and non-interval metered data from front-end systems. Validation of all imported data is then performed, based on a suite of test rules including interpretation of status codes from front-end systems. All values tested to be suspect, missing or having an error are then corrected by running through a suite of standard or customized methods. Version control and event logs make it possible to store and track all original and corrected values. When corrected values are established, they are stored in a data warehouse for further processing.

Powel MDMS includes a meter device manager regarding installation, testing, changes and disconnection of meters. The system is flexible and makes it possible to cover all kind of meter devices. It also includes functions for providing work orders and route planning for meter reading.

Using ***Powel MDMS*** you will achieve a full overview and control of processes involving metered data and time series in general. You will be able to exchange data with third party systems applying file formats and protocols. Benefits are reduced costs, improved quality in data management, reduced manual routines and more satisfied employees.

Powel MDMS includes configurable validation of metered data where corrections are traceable – and stored as an event log.

Powel MDMS is a very comprehensive and flexible solution for management of metered information and meters. It is well proven in deregulated power market surroundings, and is permanently developed with new functionalities and technologies.

Powel MDMS is serving electricity as well as heat, gas, water and other metered data.

Powel MDMS holds skilled features regarding possibilities to configure reports and calculations based on metered data. This is a feature valuable for business processes in changing surroundings. Exchange of market information for balance and settlement purposes is efficient performed thanks to a powerful toolbox for calculations and communication. More efficient management of meter devices will reduce costs and stimulate to efficient working processes in your metering business.

You may operate ***Powel MDMS*** as a part of an integrated solution making it efficient to apply metered information for the every day operation of demand forecasting and power market bidding.

Main features of Powel MDMS

Powel MDMS is a stand alone system possible to integrate with several products that are tailored to benefit distributors, suppliers, balance responsible, large end use customers, and system operators. Some major features of the ***Powel MDMS*** are:

- Import of time series from all known file formats/protocols from multi-front end data collecting systems.
- Import of manually read metered values.
- Traceable validation and correction of all imported data – performed automatically or manually following customized rules.
- All imported data streaming into a single, central repository known as a meter data warehouse.
- Event log for all changes of information in data warehouse.
- Logistics and work orders for management of meter devices.
- Data calculations and statistical reports.
- Energy and customer information transferred to other applications like billing, trade and risk systems.
- Data exchange with other market participants using EDI-solutions with EDIEL messaging.
- Calculation of load profiles aggregated for each supplier.
- Load profile grouping and aggregation for settlement and balance purposes.

Powel MDMS is linked to Powel Time Series Manager (***Powel TSM)*** functionality which is the core system for a number of Powel applications. Thanks to this integration of system solutions with ***Powel TSM***, application of metered data and time series for different power market tasks is easily performed. The following integrated products add value and benefit to the system:

- **Powel Trade Organizer –** Trade organizer for balance calculations and management of contracts and trade information
- **Powel Demand –** Short and medium term demand forecast
- **Powel TSM Web –** Web interface for energy services based on time series analyses
- **Powel Bid –** Power market bidding

In addition, systems for power generation planning and optimizing (***Powel Shop***, ***Powel Sim***, and ***Powel Inflow***) apply core functionalities in ***Powel TSM***. (See http://www.powel.com/)