SMART ENERGY PRODUCTS FOR EFFICIENT DEMAND RESPONSE: RESULTS OF SWISS SMART GRID PILOT PROJECT

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ABSTRACT

This paper describes innovative energy products introduced in the frame of a Smart Grid Pilot-Project of Regional Power Supply Company in Canton Bern, Switzerland. These products are part of a home energy management tool using customized IP-based communication and a smart metering data management system. Specific features of these novel products, such as individual near real-time electricity consumption visualization and control, are described and their influence on the demand response is discussed.

INTRODUCTION

This paper presents innovative energy products allowing individual real-time electricity consumption visualization and control. These products were introduced and are being tested in the frame of the Swiss Smart Grid Pilot-Project iSMART. The project has started in Q2-2009 and is planned for the time horizon of Q4-2012. It involves several hundred residential customers in the BKW supply area (power supply company of Cantons Bern and Jura, Switzerland).

Smart energy products were designed with a scope to create a win-win situation both for customers and for the distribution company. Giving to customers incentives to modify their load profile results in an overall electricity bill reduction and provides to the Distribution Company an opportunity to optimize its procurement programs.

Designed as the customer's home energy management tool, smart energy products use a customized IP-based communication and smart metering data management system. They allow the customer to monitor, reduce or shift his energy consumption on a daily and a weekly basis.

In the following sections, we outline the principles of demand-side management and describe the mapping of the energy products to specific demand response types. Further, we present the details of the products' features and give examples of their use. In the last section, the achieved demand response is analysed and the first results presented. Future product development directions are also outlined.

DEMAND RESPONSE GENERATION

Demand-side management refers to joint actions undertaken by utility and its customers with the aim of energy efficiency increase. Power utilities aim to reduce peak and base loads by influencing the customer's energy use profile through financial, environmental or reliability incentives.

Some of the load-shaping objectives are : general reduction of utility loads (energy conservation), reduction of the peak load (peak clipping), increasing the off-peak load (valley filling), shifting the load from peak to off-peak periods (load shifting), or shaping the load depending on power system conditions (flexible load).

In the context of the iSMART project, two demand-response methods were implemented: Energy Conservation and Load Shifting. In the next sections, these methods and corresponding products are outlined.

Energy Conservation

Energy conservation refers to reduction of energy consumption (fig. 1), which can be achieved through energy efficiency actions as well as more extensive use of renewable energy sources. These actions help to offset the growth of conventional energy supply.

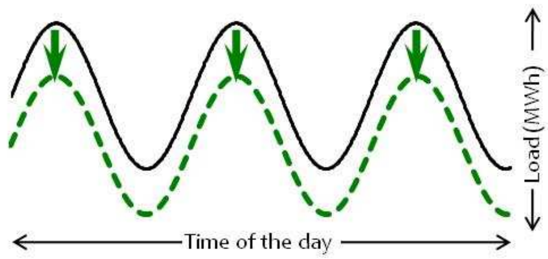

Fig. 1. Generating Demand Response: Energy Efficiency

Load Shifting

Load shifting refers to the modification of energy use patterns so that on-peak energy consumption can partially be shifted to off-peak periods. (fig. 2)

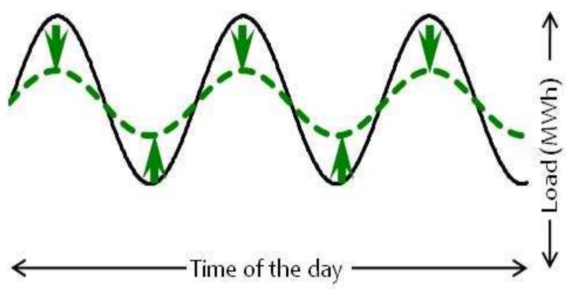

Fig. 2. Generating Demand Response: Load Shifting

ENERGY PRODUCTS DESCRIPTION

In order to implement the above explained demand-management techniques, two tailored energy products were designed: VISU, for an overall energy conservation, and SMART, for intelligent price-based shifting of domestic load from high-tariff to low-tariff periods.
Both products include several modules, such as real-time power consumption monitoring, daily energy use visualization, history over different time slots, comparison with own past consumption patterns, forecast of likely energy consumption and warnings about high level of use, as well as additional information such as energy tips and tricks. We used several incentive systems, such as different tariff models, individual consumption forecast, "red-light"-visualization and a target-setting tool. This multi-incentive system was then linked to a rewarding point-accumulation method introducing game elements and leading to a target-based behavior. Products were introduced on several different visualization supports such as a dedicated web portal, a home display and mobile smart-phone applications. In the following section, we describe details of implementation and interactions of product modules, and then show examples of their use. Calculation Basis: Standard Load Profile, 3 years data, samples at 15 min intervals.

Details of the VISU Implementation

The "VISU" Product was adapted to the needs of low energy consumption homes, typically apartment buildings, seeking an overall energy bill reduction. It includes following features:

- Normal/Turbo Metering Mode;
- Weekly Consumption Objective Setting;
- Red Light Consumption Indicator;
- Energy-Points System for Energy Efficiency;
- History;
- Tips & Info.

Normal/Turbo Metering Mode

The default metering mode of 15 min intervals was implemented. The customer can track its load/costs curve based on last 8 intervals (fig. 3).

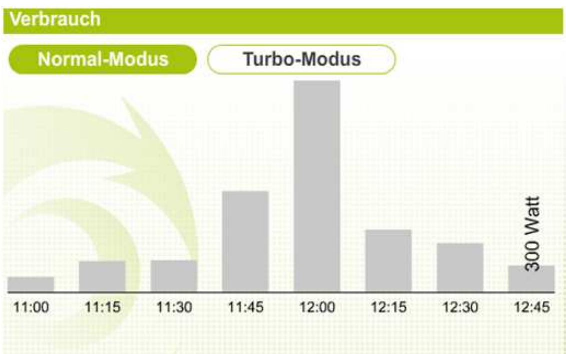

Fig. 3 Elements of product VISU

The load curve represents the sum of all appliances of the household and is derived as a difference between cumulative energy measurements at two intervals t_1 and t_2:

$$P = \frac{E(t_2) - E(t_1)}{t_2 - t_1} \tag{1}$$

In order to include the real-time consumption feedback and to give a customer a possibility to track individual loads, a quasi real-time metering mode was implemented (*turbo-mode*). In this mode, the actual consumption is measured at intervals ≤10 sec. As the cumulative energy measurements at that interval are under the wished resolution threshold, the power curve is calculated from exact phase current and voltage measurements and is derived from:

$$S = I_A \cdot U_A + I_B \cdot U_B + I_c \cdot U_C, [kW] \tag{2}$$

taking into account the residential load factor.

Energy Budget and Weekly Consumption Goal Setting

Fig. 4. Consumption objective and red-light feedback signal

The weekly energy budget chart (fig. 4) refers to the amount of energy normally consumed within a given week by a customer belonging to a given group, scaled to an individual average yearly consumption. It is calculated as follows:

$$E_w(w) = \frac{E_{year}}{52} \cdot f_{corr}(w) \tag{3}$$

where:
E_w is weekly energy consumption of a household, for a given week of the year, (w=1-52);
E_{year} is the average yearly consumption of a given household (based on the records of the 3 last years);
f_{corr} is budget correction factor accounting for the seasonal energy consumption pattern and based on the standard load profile of a given customer group.
E.g. If the average yearly consumption of a given customer is 3'500 kWh, the corresponding average weekly consumption is $E_w(w)=E_y(y)/52 = 67.3$ kWh. The correction factor of the week w=40 is calculated to be $f_{corr}(w)=1.04$. Therefore, the budget E_w for the week 40 for this customer is: $E_w(40) = 67.3$ kWh * 1.04 = 70.0 kWh.

Goal-Setting Function
The customer can reduce its weekly energy consumption by setting a weekly goal of consumption reduction (displayed as an arrow on fig. 6). For example, the weekly goal that is set at -7% displays an arrow at 93% of the weekly energy budget (in the previous example, at 70.0 kWh * 0.93 = 65.1 kWh).

Red Light Consumption Indicator (RLI)
The red light symbol is used as an indicator for a deviation of a given household energy consumption forecast from its weekly energy budget, based on cumulated values. RLI is updated hourly and could be calculated with or without taking into account the goal setting function. It helps a customer to assess its ongoing energy consumption and to take corrective actions in order not to exceed its weekly energy budget.
Red Light Indicator with Goal Setting. The RLI is set to green if the actual consumption forecast is lower than the energy budget by 2.5%. The RLI turns to yellow if the difference between the actual consumption forecast and the budget setting scores is ±2.5%. If the difference between the cumulated actual consumption forecast and the weekly budget exceeds 2.5%, the RLI is set to red.
Red Light Indicator with Goal Setting. The RLI is set to green if the actual forecast value is lower than the actual energy consumption goal. If the forecast lies within the interval between the goal and the budget, the RLI is set to yellow. If the forecast exceeds the budget, it is set to red.
The RLI value is calculated starting from 12:00 noon on Monday.
Forecasted consumption value is calculated based on hourly standard load profile values (scaled to the actually metered consumption of a given household) and on an average deviation from the budget. For example, if the average deviation for the hour h=12 scores 4.64% while the absolute budget value equals 70.02kWh , the next forecast is calculated to be:
E_{fc}=70.02 kWh * 1.0464 = 73.2 kWh.

Energy-Points System for Energy Efficiency
The actual energy consumption reduction is stimulated trough an energy-points system. Points accumulation is rewarded with awards available from the project virtual shop.
The total energy-points score is calculated differently depending on whether the weekly goal setting function was used or not.
Energy-Points calculation without Goal Setting. The calculation is completed weekly (Sunday 12:00 p.m. midnight). If the RLI is green, the customer collects energy-points (5 energy-points per % of consumption reduction). A yellow RLI position does not give points, while the red light indicates negative energy-points (-2.5 points per % of exceeded consumption).
Example. With a total of 67 kWh metered weekly energy consumption (95.7% of the weekly budget if E_w=70 kWh), the customer reduced its actual energy consumption by 4.3%. Taking into account 2.5% in yellow interval which does not score points, the actually rewarded reduction is +1.8% and scores up to 9 points (+1.8% * 5 pts). In the opposite case, if the household exceeds its weekly budget by 4.3% (73 kWh in absolute values), the penalty would be calculated in terms of energy-points as follows: -1.8% * 2.5 pts = -4 pts.
Energy-Points calculation with Goal Setting. If the goal setting function is used by the customer, the actually metered weekly energy consumption in yellow or green interval scores energy points (between 5 and 10 pts per % of consumption reduction), while red interval "clearing" means points subtraction from the total score (-2.5 energy-points per % of exceeded consumption). The calculation is analogous to the example above.

Details of the SMART Implementation

The "SMART" product is primarily designed for individual house owners, which exhibit large amounts of electrical home facilities and thus represent a considerable potential of shiftable load.

Load-Shifting Tool
The chart in fig. 6 below enables the visualisation of the energy consumed during the high-tariff (red chart) and low-tariff (green chart) periods. During the actual consumption, metered values are filled in the corresponding "container". The customer can switch between the weekly and daily views and is able to compare its actual values to the average.

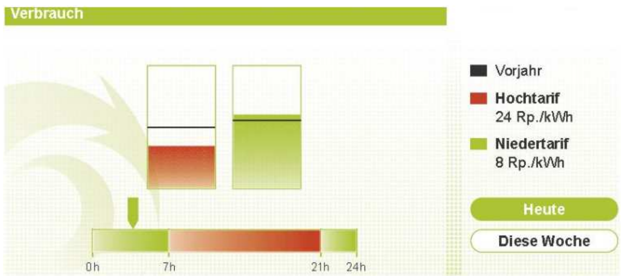

Fig. 5. Elements of load-shifting product

Energy-Points System for Load Shifting
At the end of the week, the cumulated consumption values are compared to the average yearly values (black marks, fig. 8) and if the high-tariff-related consumption is lower than the yearly average, the difference is rewarded with energy-points similar to the previously explained method in the VISU product section. The idea is here to reward load-shifting from high-tariff (red container) to low-tariff hours (green container).

EVALUATION METHODS AND FIRST RESULTS

The evaluation of changes in customer behavior associated with each product was based on a quantitative and qualitative comparison of samples from active pilot-customers and from control-group participants (reference load profile). Statistical changes in load patterns as well as log information about the effective use of tool modules were integrated with an assessment of customer experience with new energy products. Aspects such as acceptance, daily use, short- vs. long-term learning effects were also addressed. Further study will be dedicated to the scaling of the pilot-project results to the whole distribution area, customer segmentation and the evaluation of the roll-out of potential products.

Qualitative Results

From the study conducted directly with a group of customers, the following preliminary qualitative results were drawn. Benchmark and history were judged to be the most important functions outweighing the actual on-line energy metering chart. Percent deviation feedback in relative values are considered more efficient compared to absolute values as it is possible to immediately derive the need for corrective actions.

Quantitative Results

Our studies of goal-oriented behaviour among the pilot-customers show that goal-related motivation has broad sources.

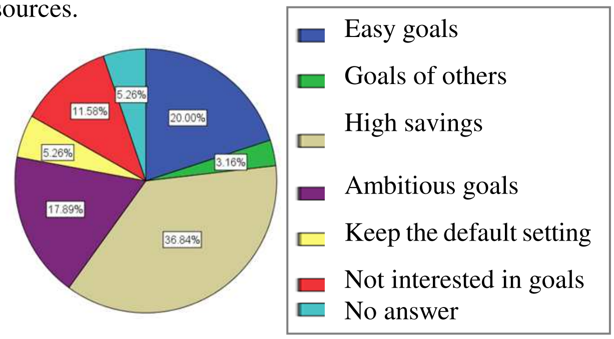

Fig. 6. Pie-diagram of the goal motivation among pilot customers

About 20% of the customers are only motivated if the goals are easy. However, nearly 40% of the customers are interested in possible savings of energy as well as costs. Almost 19% of customers set objectives "for fun", while some 12% are not interested in any goals. Further, among customers who use the goal setting function, over 60% consider the actual goal achievement highly important.

CONCLUSIONS

In this paper, we described innovative energy products allowing individual real-time electricity consumption, visualization and control, implementing demand side management techniques such as energy conservation and load shifting. The smart-metering infrastructure implemented in this pilot-project, allowing for two-way communication and quasi-instantaneous feedback, is also presented.
Using up-to-date pilot-project results, we demonstrate how smart energy consumption feedback tools can become a powerful instrument of demand response, enhancing energy efficiency, customer awareness and transparency while allowing the introduction of more CO_2-neutral energy sources and ultimately generating added-value for both energy providers and consumers.

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