Field Trials towards Integrating Smart Houses with the Smart Grid

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Summary. Treating homes, offices and commercial buildings as intelligently networked collaborations can contribute to enhancing the efficient use of energy. When smart houses are able to communicate, interact and negotiate with both customers and energy devices in the local grid, the energy consumption can be better adapted to the available energy supply, especially when the proportion of variable renewable generation is high. Several efforts focus on integrating the smart houses and the emerging smart grids. We consider that a highly heterogeneous infrastructure will be in place and no one-size-fits-all solution will prevail. Therefore, we present here our efforts focusing not only on designing a framework that will enable the gluing of various approaches via a service-enabled architecture, but also discuss on the trials of these.

Key words: smart grid, web service, smart metering

1 Motivation

In order to achieve next-generation energy efficiency and sustainability, a novel smart grid Information and Communication (ICT) architecture based on Smart Houses interacting with Smart Grids is needed. This architecture enables the aggregation of houses as intelligent networked collaborations, instead of seeing them as isolated passive units in the energy grid.

The research project SmartHouse/SmartGrid takes a fundamentally different and innovative approach where the ICT architecture under development by the consortium introduces a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment [3]. This concept (as depicted in Figure 1) seriously considers smart homes and buildings as proactive customers (prosumers) that negotiate and collaborate as an intelligent network in close interaction with their external environment [4]. The context is key here: the smart home and building environment includes a diverse number of units: neighboring local energy consumers (other smart

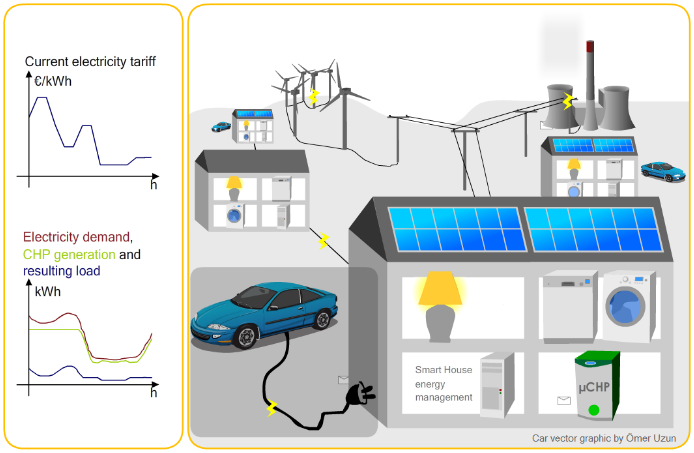

Fig. 1. The SmartHouse/SmartGrid vision

houses), the local energy grid, associated available power and service trading markets, as well as local generators, e.g. environmentally friendly energy resources such as solar and (micro) common heat and power (CHP) plants etc. The SmartHouse/SmartGrid approach is based on a carefully selected mixture of innovations from recent R&D projects in the forefront of European smart grid research. These innovations include:

- In-house energy management based on user feedback, real-time tariffs, intelligent control of appliances and provision of (technical and commercial) services to grid operators and energy suppliers.
- Aggregation software architecture based on agent technology for service delivery by clusters of smart houses to wholesale market parties and grid operators.
- Usage of Service Oriented Architecture (SOA) [5] and strong bidirectional coupling with the enterprise systems for system-level coordination goals and handling of real-time tariff metering data.

The main technical measures on which the functionalities of the ICT architecture are based include:

- End User Feedback: Aims at an interface to the end user in order to give feedback on his/her energy behavior and on the availability of (local) clean electricity.
- Automated Decentralized Control of Distributed Generation and Demand Response: Aims at a better local match between demand and supply, at customer acceptance of management strategies, and at a more effective reaction to near-real time changes at the electricity market level (e.g. due to fluctuations in large-scale wind energy production) and grid operations (e.g. for congestion management and reserve capacity operations).
- Control for Grid Stability and Islanding Operation: Aims at the delivery of services by smart houses to be used by network operators to maintain or restore

stability in (distribution) networks in an active manner. Here, the particular focus is on: (i) the capability to run local power networks in islanded mode and (ii) reaction of end-user systems to critical situations in the grid.

2 Field Trials

Several trials will be under realization in the course of 2010 and beginning of 2011. We consider them to represent possible constellations in the future smart grid infrastructure. In the ideal case, there would be three single instances of a common SmartHouse/SmartGrid framework. In reality, however, each field trial is bound to several – also architectural – restrictions that arise from the context in which the experiments are carried out. These restrictions result from existing partnerships and parallel related trials that the SmartHouse/SmartGrid members are engaged in. In those cases where different technological solutions have been chosen for realizing similar functionality, a comparative analysis of the technologies will be conducted at the end of the SmartHouse/SmartGrid project, with the aim of identifying the best solution for a given set of framework conditions.

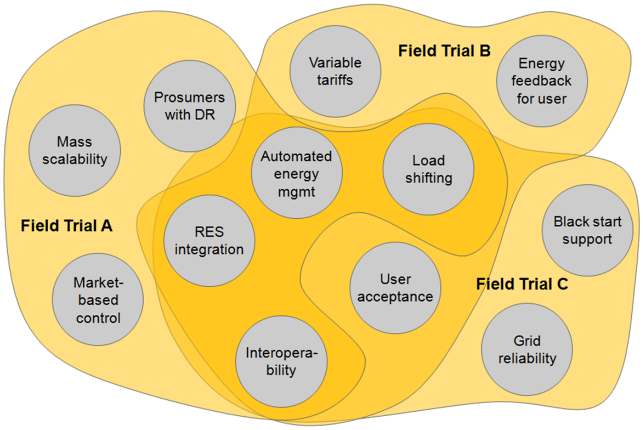

Fig. 2. Complimentary foci of the SmartHouse/SmartGrid trials

2.1 Field Trial A

The cluster of smart houses is located in Hoogkerk, a city in the Netherlands. The end-user systems integrated in the test installation consist of (any combination of) micro-CHPs, heat pumps for domestic heating and electricity intense domestic appliances. To all systems, an intelligent software agent will be associated, running for instance on a programmable intelligent meter. The agent communicates operating preferences to the aggregating level.

The main idea is to integrate existing real households and devices, but also to simulate them in order to make a large-scale test of SmartHouse/SmartGrid concepts with respect to the enterprise integration. We have to make sure that future business solutions will be able to adapt to high-volume data and still be able to deliver high-quality reliable services and near real time processing and views on the acquired information. As such, simulators will be built for several layers and will mimic their behavior by e.g. amplifying in a non-deterministic way the data acquainted from real-field i.e. the real households. A main challenge will be to integrate the infrastructure for near real-time control, requiring frequent and time-constrained communication via low bandwidth, with an infrastructure for variable tariff metering, information handling and billing, based on collection of large volumes of data on a non time-constrained base, e.g. once per month. Both application areas require a reliable and robust infrastructure that connects smart houses with enterprise systems, the so called smart grid.

The problem statement for field trial A can be described as follows: How can we connect and utilize mass scale aggregations of smart houses for support of business operation, such that the interests of different stakeholders are respected as much as possible and as fair as possible? Connection of aggregations of smart houses will focus on the smart grid infrastructure needed for communication and information exchange between the smart houses and the enterprise system(s). The main concepts that will be used are multi-agent i.e. the PowerMatcher [2] systems and web services to communicate information. The infrastructure has to support mass scale participation of 100,000 to 1,000,000 households in an enterprise business application that focuses on near real-time control of household appliances based on variable tariffs. Qualification and quantification of the interests of different stakeholders has to be made, based on energy efficiency enhancement and cost / benefit improvement.

2.2 Field Trial B

The main technical goal of field trial B is to demonstrate how private customers can be motivated to adjust their consumption by load-shifting when they are offered variable electricity tariffs on a day-ahead basis, and how to organize such a system to be applicable for a larger number of customers. The load shifting of non user-controllable loads (e.g. freezers) will be carried out automatically by a system situated at the customers premise, the ISET-BEMI+ [3]. This system comprises a computing core, switching elements for automated load switching and for load supervision (switch boxes), and a visualization functionality. The latter allows the customer to view the variable tariff and thus to manually optimize the operation of user-controlled loads (e.g. cooking appliances) in addition to the automatic optimization. Customers also receive up-to-date information on their energy consumption and cost based on at least hourly values (total) and high-resolution data based on single-device-measurement from loads connected to switch boxes. This is expected to additionally raise customers awareness on the topic of energy efficiency.

The BEMI-equipped customers are given a variable tariff by an energy supplier which operates a Pool-BEMI. The details of the variable tariffs given to the customer are currently under discussion but will be based on day-ahead hourly power prices. By operating devices in times where these prices are low, the customer gets the opportunity to optimize his energy cost. The ISET-BEMI+ automatically carries out this optimization. This shall cause an overall load shift into times where prices from energy markets are low, thus demonstrating that the cost for energy procurement carried out by the energy supplier is lowered as well. It has to be considered that energy costs per kWh generated is low in times of high infeed from generators with zero fuel cost, e.g. wind turbines. Thus, variable tariffs allow the customer to profit from price fluctuations while allowing the energy provider to shift loads such that energy from renewable sources, or in more general at times of a surplus of electricity generation, is preferably and efficiently used. Also, it is expected that this also will reduce balancing energy for deviation of customer consumption from the predicted demand and to reduce peak power in the distribution grid area considered, which again yields economical benefit for grid operator and energy supplier.

Finally a more balanced grid with reduced peak consumption will reduce “stress” in the grid, and allowing for a reduced assumption for maximum power needed in a grid. Hence, there are physical limits for load shifting which stem from restrictions of the loads parameters on one side and the willingness of customers to cooperate on the other. It is yet to learn more about such limits for load shifting given a system of ISET-BEMI+ operating in an urban grid area. The field trial is designed to provide data in order to be able to research these questions. Furthermore, the field trial will provide information and experience in order to identify architecture and technological, economic and regulatory needs for a mass roll-out of energy management systems in the future.

However, it should be noted that the proper implementation of such a field trial will also show the problems and limits that need to be considered if dealing with real customers. Not only does the acceptance of such systems by customers need to be explored, but also their degree of understanding and willingness to study and use any data provided. Not all data available is appropriate to present to an average customer without over-stressing his cooperation possibilities and willingness. Finally, through un-bundling and many competing energy and service providers in Germany, there are many stakeholders to be included in the process.

2.3 Field Trial C

In field trial C the several business cases are combined. We focus on (i) distribution grid cell islanding in case of higher-system instability, (ii) black-start support from smart houses, (iii) integration of forecasting techniques and tools for convenient participation in a common energy market platform, (iv) aggregation of houses as intelligently networked collaborations, and (v) distribution system congestion management.

The problem statement for field trial C is to identify how can the smart house support the grid in case of emergency in an energy market environment. The smart house should include some functionalities in order to deal with emergency and critical situations. This operation includes two phases: the first phase is before the unexpected event and during that phase the team of houses, to which all the customers equipped with the load controller belong to, should make some preparation actions.

The second phase is during the event where the system should decide the actions for fast restoration. This scenario suggests that the aggregator and the distribution network operator (DNO) interact with the smart houses. They should provide to the system the proper information in order to react correctly during the emergency case. However the critical part is that the network of smart houses should have a level of autonomy and decide by itself the overall system management. Furthermore since the system assumes the existence of an energy market it is obvious that the energy consumed/shed during any operation should be monitored. Here again a multi-agent system will be used i.e. the Magic system [1].

3 Discussion

Several aspects of the future SmartHouse/SmartGrid vision are analyzed in all three field trials. Other aspects are specifically tackled in one or two trials only. The most important technological goals of the SmartHouse/SmartGrid solutions, which will be similar across trials, are the following: (i) Automated energy management, (ii) Variable tariffs, (iii) Integration of renewable energy sources and (iv) Interoperability. Other aspects, such as user acceptance, the impact of energy feedback on user behavior or variable tariffs, are also relevant in all three trials, but are only investigated in a structured way in one or two trials. Besides, the analysis of some aspects are deliberately allocated to one specific trial, such as mass-scalability and market-based control (trial A) or black start support and islanding (trial C).

In the SmartHouse/SmartGrid projects, three different technologies for managing demand and supply in a way to realize the goals of an energy efficient, flexible and sustainable smart grid are developed. In this document, the commonalities and differences between the three technologies are reviewed, and conclusions for a common architecture are drawn. Table 1 summarizes the main characteristics of the three technologies PowerMatcher, BEMI and Magic while Table 2 provides an overview of the different methodologies.

As depicted in Table 1 and Table 2, it can be recognized that the common idea of the SmartHouse/SmartGrid implementation follows a unified approach: PowerMatcher, ISET-BEMI+ as well as Magic manage demand and supply on the basis of a centralized optimization tool that works with decentralized decision making. This is highly important for the acceptability of these technologies each participant keeps full control over his devices, but has incentives to align the device operation with the global status of the overall system. Several challenges

Table 1. Concept comparison of technologies

	Trial A: PowerMatcher	**Trial B: BEMI**	**Trial C: Magic**
Local control	Decentralized decisions about consumption and production	Decentralized decisions about consumption and production	Decentralized decisions about consumption and production
Basis for decision-making	Centralized market equilibrium of all bids	Centralized tariff decision	Centralized negotiation of requests
Control objective	Real-time mapping of demand and supply	Shifting demand to times of low-cost supply	Mapping of demand and supply in critical grid situations
Trial specifics	Scalable architecture	User-information for manual control of consumption behavior	

have already been identified and will be investigated also during the trials, as depicted in Table 3.

Table 2. Methodology comparison of technologies

Trial A: PowerMatcher	**Trial B: BEMI**	**Trial C: Magic**
– Market-based concept for demand and supply management – General equilibrium theory – Market is distributed in a tree structure – Participants: devices, concentrators, objective agents, auctioneer – Device agents submit bids / demand and supply functions	– BEMI enables decentralized decisions based on tariff information – Decision based on local information about devices and central information about variable prices – Pool-BEMI sends price profiles – Avalanching can be avoided by giving different price profiles to different customer groups – Day-ahead announcement of price profiles	– MAS-based using JADE (negotiation-based) – Grid announces SP/BP – MG tries to agree on better prices – Maximum of internal benefit – Based on symmetric assignment problem

Each of the three technologies is based on the concept to map the consumption demand to the producible or produced energy. On the one hand, the consumed energy amount needs to be adjusted in an appropriate way. This adjustment of the energy amount to be consumed is possible by deploying several features like automatically switching on and off consuming devices or manually influencing the consumers behavior. These features are part of all the three architectures especially the automated switching of the controllable devices in the households. The control of the shiftable production of energy is in a similar way possible by means of automated on and off switching features for e.g. CHP producers.

Table 3. Challenges per Technology

Trial A: PowerMatcher	**Trial B: BEMI**	**Trial C: Magic**
Definition of demand functions	Definition of price profiles	Fixed negotiation periods
Triggering of new rounds problem was solved using an event based market concept	High-quality forecast of customer reactions to price profiles	Scalability
Effectiveness if real-time price is not binding for the customer?	Congestion management might be limited due to lower price limit	

Each of the concepts includes a central negotiation or calculation mechanism that tries to map the producible energy to the consumable energy for all sources (smart houses and production sites) within the enclosed smart grid. External production sites producing and providing a certain amount of energy can be included in the negotiation process as a fixed and non-controllable amount of energy. Therefore, the architecture of all three set-ups contains a negotiation tool or balancing tool as depicted in Figure 3.

The way how the three used negotiation or balancing tools are designed is similar from a high-level perspective, but different in the details. Each tool either collects information or forecasts the desired amounts of energy to be consumed or produced from all participating smart houses and production sites. Each tool is able to understand besides the desired energy amounts some indicators that state under which conditions the energy will be consumed or produced. One condition is used for all of the three tools: It is a piece of information about the desired price, if energy is shiftable. After having collected all offers and requests, the tool analyzes how the equilibrium can be reached under the given conditions.

One major difference between the negotiation procedures is the time interval for the repetition of the negotiations and therefore for the consideration of unforeseeable changes. The PowerMatcher and also the Magic system can work in (near) real-time. The advantage is that for unforeseeable demand or production requests a short reaction time can be expected to map the complementary production or demand requests. The BEMI technology, in contrast, works on a time scale of a day, where dayahead considerations of production and consumption patterns are done in order to define the price levels that act as decision guiding signals. Intraday redistribution of price profiles is possible, but not done on a regular basis.

Finally, the field trials will demonstrate if a lower repetition of equilibrium calculations is sufficient. The near real-time negotiation causes a high degree of scalability and performance requirements. The PowerMatcher tool does the

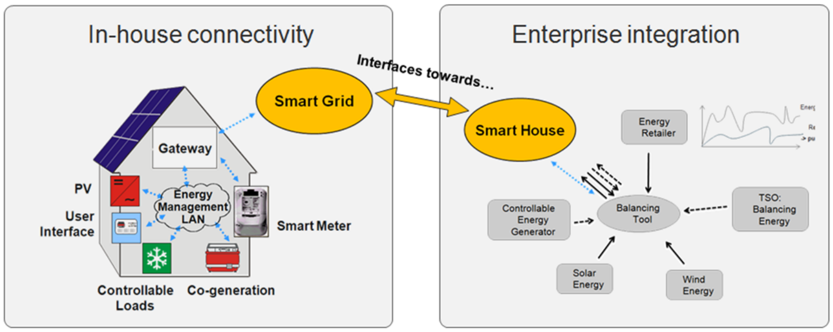

Fig. 3. Connection between the in-house architecture and its integration within enterprise processes

real-time negotiation using a multi-level approach realized by the use of agents clustering several smart houses or concentrator levels stepwise. For a lower number of smart houses, the concept of real-time could scale easily, but for a higher number of smart houses the concept has to be proved.

Decentralized decisions about consumption and production are made by all of the three field trials. This fact is the main common part of the three architectures. The control of switching on or off of a certain producing or consuming device is always done within the smart house itself. Even when for the smart house a central control is established, the decision remains within the house. Of course the decision is guided by a centralized determined and provided signal (e.g. virtual price signal or a real-time tariff / price structure or direct control signals).

Historical information about the consumed energy and/or the produced energy within the smart houses and the historical price and cost information are all provided and displayed within the smart houses (i.e. per metering point). This allows the customer to adapt his behavior to the current situation in the power grid.

It is still unresolved whether all energy-consuming appliances should be integrated into the local energy management within the smart house. A quite realistic vision is that only some appropriate appliances are connected to the BEMI, PowerMatcher or Magic system. Amongst those, there can be identified devices that run a user-prepared program (i.e. washing machine), devices with thermal storage (i.e. cooler, CHP plant) or dimmable devices. Those appliances that the customer will always want to consume instantly (like, e.g., entertainment, lighting or cooking) will probably be controlled solely by the customer, just like today. An energy information portal which delivers all price and consumption data to the end customer can then give the information necessary for deciding about the operation of devices that are not integrated into the energy management. The customer is made aware of the current price, so that he can manually optimize the timing of his energy consuming activities.

4 Conclusions

Innovative technologies and concepts will emerge as we move towards a more dynamic, service-based, market-driven infrastructure, where energy efficiency and savings can be facilitated by interactive distribution networks. A new generation of fully interactive Information and Communication Technologies (ICT) infrastructure has to be developed to support the optimal exploitation of the changing, complex business processes and to enable the efficient functioning of the deregulated energy market for the benefit of citizens and businesses.

We do not expect that an one-size-fits all technology will prevail in the market; we rather consider that several of them will coexist and the real challenge would be to integrate them in a global ecosystem that will deliver the envisioned smart grid benefits. To this end the SmartHouse/SmartGrid project has designed and will realize in real world three field trials, each of them testing several aspects vital towards making the smart grid vision a reality. We have shown here in detail the motivation behind them, the considerations but also the challenges that may lie ahead. On the basis of the results and experiences from these field experiments, we will define a roadmap focused toward a mass-market application.

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