FIELD-TESTING SMART HOUSES FOR A SMART GRID

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ABSTRACT

The current electricity distribution system treats home and working environments as consisting of isolated and passive individual energy-consuming units. This severely limits the achieved energy efficiency and sustainability, as it ignores the potential delivered by homes, offices, and commercial buildings which are seen as intelligent networked collaborations where energy can be intelligently managed. The Smarthouse/SmartGrid project is developing an ICT architecture introducing a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment. Smart homes and buildings are considered as (i) proactive customers that (ii) negotiate and collaborate as an intelligent network in (iii) close interaction with their external environment. Three interrelated field experiments validate and demonstrate the ICT architecture in real world home and working environments. The initial results show that the newly developed control strategies and network architectures (i) enhance energy efficiency, (ii) improve efficient management of local power grids (e.g. improve network load factors) and (iii) enable the integration of a larger amount of renewable energy resources with less carbon emission impact.

INTRODUCTION

The residential, Small Office/Home Office (SOHO) and commercial building sector together is responsible for over 50% of Europe's electricity consumption. The current electricity system does not include active collaboration of parties such as homes and buildings. This severely limits the effectiveness of energy management efforts. In order to achieve next-generation energy efficiency and sustainability, a novel smart grid 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 ICT-driven approach of the SmartHouse/SmartGrid project [7] introduces a holistic concept and technology for smart houses as they are situated and intelligently managed within their broader environment (depicted in Figure 1). This concept seriously considers smart homes and buildings as (i) proactive customers ("prosumers") that (ii) negotiate and collaborate as an intelligent network in (iii) close interaction with their external environment. The key motivation stems from the fact that the smart home and the smart building environment include a diverse number of units: neighbouring local energy consumers (other smart houses), the local energy grid, associated available power and service trading markets, as well as local producers such as environmentally friendly energy resources such as solar and (micro)CHP etc. By considering collaboration and information sharing among them, better energy efficiency can be achieved.

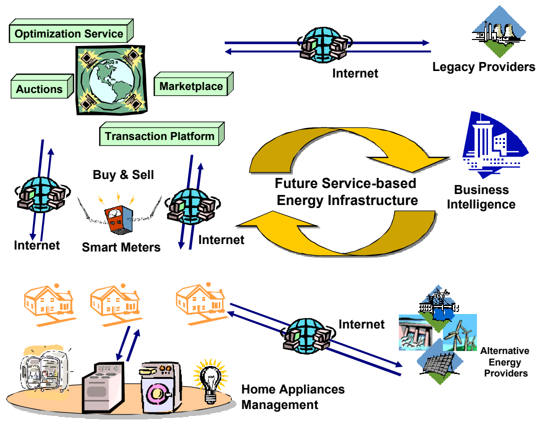

Figure 1: Service-based ecosystem based on Smart Houses and Smart Grids

Our architecture is based on a carefully selected mixture of innovations from recent IT and energy 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 [1, 2, 3].
- Aggregation software architecture based on agent technology for service delivery by clusters of smart houses to wholesale market parties and grid operators. [4, 5].
- Usage of Service Oriented Architecture (SOA) and bidirectional coupling with the enterprise systems for system-level coordination goals and acquisition and evaluation of real-time metering data. [6].

Three interrelated field experiments validate and demonstrate the ICT architecture in home and working environments. The experimental preliminary results show that the newly developed control strategies and network architectures (i) enhance energy efficiency, (ii) improve efficient management of local power grids (e.g. improve network load factors) and (iii) enable the integration of a larger amount of renewable energy resources with less carbon emission impact.

ICT-ACRHITECTURAL TESTING

Field test A does a validation of multi-agent system-based aggregation [5] of smart houses for energy efficiency enhancement and electricity trade optimization utilizing real-time variable tariffs. Additionally, it tests the high performance information exchange of such a system with Enterprise services (e.g. for billing) at data traffic levels of mass-application (~1,000,000 customers). In order to test architecture scalability, the data traffic from a real-life cluster of smart homes in The Netherlands is combined with mimicked data sources in order to reach the desired data traffic.

Field Test Set-up

The field test implements a virtual power plant (VPP) for near-real-time balancing on a time scale of a few minutes up to several hours. The PowerMatcher smart grid technology (www.PowerMatcher.net) forms the basis of the VPP. This technology is capable of optimizing over high numbers of small units: distributed generators, responsive demand and electricity storage.

To achieve the large scale required, we integrate existing real households, but also hardware simulate the behaviour of many others. As such, simulators are built for several layers and mimic their behaviour e.g. by amplifying in a non-deterministic way the data acquainted from real-field i.e. the real households.

The architecture connects to the PowerMatchingCity cluster of smart houses located in Hoogkerk, in the Netherlands as established in the INTEGRAL project (www.integral-eu.com). The end-user systems integrated in the test installation consist of micro-CHPs, heat pumps for domestic heating and electricity intense domestic appliances. To all systems, an intelligent software agent has been associated, running on a programmable residential data gateway. The agent communicates operating preferences to the aggregating level. Measurements gathered are submitted to an enterprise metering service over the Internet as depicted in Figure 2.

Preliminary Results and Lessons Learned

The experimental results so far indicate sufficient adaptation of the agent system controlled infrastructure, as well as efficient interaction with the business systems. The PowerMatcher software has shown to perform smooth and stable under mass application circumstances. We have shown that running a virtual power plant and collecting metering data for a real-time tariff can be performed using a combined ICT infrastructure. The first is a low-bandwidth, fast-reacting task, while the latter involves a bulk metering data transfer for a real-time tariff with a resolution in the 5-to-15 minutes range.

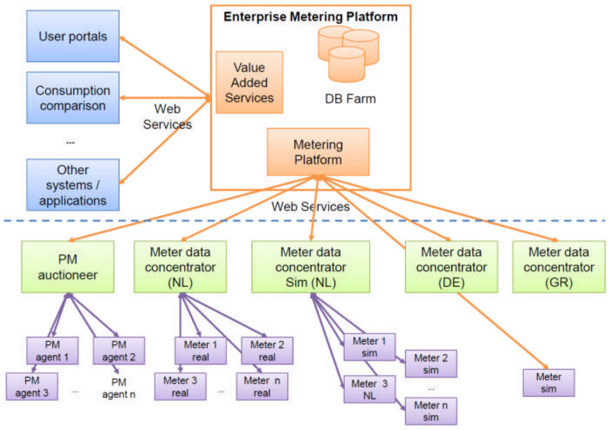

Figure 2: Enterprise Integration and smart metering performance evaluation

Additionally on the enterprise performance side we were able to acquire results that show the scalability and performance of the system under the mass application conditions. We have shown [6] that high resolution metering correlating to several millions of meters can be supported with a limited number of concentrators and enterprise data management systems. We are confident that these limits can be further pushed if one more coherently takes advantage of software and hardware tuning, which would be of interest to commercial solution providers.

The main challenge has been to integrate the infrastructure for near real-time management, requiring frequent and time-constrained communication of low bandwidth messages, 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, which is a key vision of the emerging smart grid.

AUTOMATED RESPONSE TO PRICE SIGNALS

Field test B aims at introducing and testing a system for demand-side management based on electricity price signals. Furthermore, it checks the possibilities for load shifts based on price incentives and automated energy management. In the city of Mannheim in Germany a cluster of approx. 100 smart houses participate. The private customers are offered variable electricity tariffs on a day-ahead basis. These tariffs will incentivize load-shifting of user-controllable loads (e.g. dish washers) and non user-controllable loads (e.g. freezers) controlled automatically by a system situated at the customer's premise. The user interacts with the system via a decentralized web portal (depicted in Figure 3), thus can change his consumption behaviour for lowering energy bills. The energy provider and grid operator (DSO) on the other side use the system for operational electricity supply optimization, e.g. maximum utilization of renewable or decentralized energy sources.

Field Test Set-up

The field test installations comprise components at the customer's premises ("Energy Butler" gateway [1], communication and control components), a higher-level "Pool-BEMI" computing day-ahead tariffs as well as various servers for aggregating and distributing tariffs, customer metering data, Energy Butler software management messages and updates. The Energy Butler gateway is an embedded Linux PC highly optimized for low-power operation, running a newly developed, manufacturer-independent and open source middleware being developed by the OGEMA initiative (www.ogemalliance.org). This field test will continue also after the SmartHouse/SmartGrid project [7] conclusion, within the German project "Modellstadt Mannheim" (www.modellstadt-mannheim.de), aiming at including over 1000 customers in a cellular structured electronic energy market.

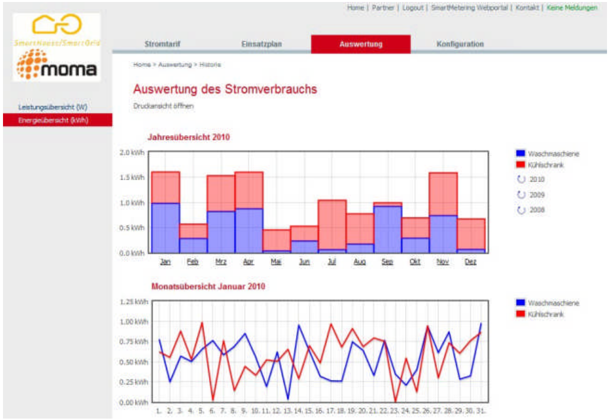

Figure 3: Energy Butler info at customer portal

Preliminary Results and Lessons Learned

As the field test has recently started, no results from the evaluation are available so far. However, there are various lessons to be learned from the installation phase itself. On the software side, one of the most important results is that the OGEMA Framework, being developed and field tested within the SmartHouse/SmartGrid project for the first time, proves to be an adequate basis for the flexible implementation of building energy management systems. Approaches for architectural enhancements of the framework resulting from the implementation are currently used for further development of the OGEMA reference implementation. For example, the next generation communication system interface will offer enhanced support of node-based meshed networks like Z-Wave, which is also used in this field test B.

A unique feature of the field test B is that it involves many stakeholders acting profit-oriented in the unbundled market. An important lesson from this is that the emergence of these stakeholders (from what once were single utilities) greatly increases mediation issues when implementing smart grids. Within the project context, this is resolved by project management and common consortium decisions. However, if considering implementation of smart grids in the unbundled market of today, such a consortium would have to be replaced by a trusted cross-partner organization for mediation between conflicting partner interests which otherwise would hinder technical implementation. For example, the energy provider's interest of giving the customer a tariff bonus for incentivizing a load shift for better utilization of the DSO's grid resources, may be of advantage for the DSO, but is unattractive for the energy provider as of today. However, without technical services provided by both the smart grid cannot prevail, which is of disadvantage for both.

CRITICAL GRID SITUATIONS

Field test C demonstrates the ability of a decentralized system to handle critical situations such as the transition to island mode or the black start. Furthermore it demonstrates the decentralized provision of ancillary services such as load shedding support to alleviate network congestions. The field test C is hosted in Meltemi, a seaside camping located 15 km north-east to Athens, Greece. It consists of 170 cottages used as a camping resort mostly during summer. Due to the small size of each cottage, the electrical consumption of each house is lower than an ordinary house in Greece, however, the electrical structure (all houses connected to the same MV/LV transformer) of the settlement makes it ideal for testing, especially those aspects related to emergency and critical grid situations. The installation of a 40kVA diesel generator and 4.5 kW of PV panels form the Meltemi trial C as an interesting testbed for micro-grid issues.

Field Test Set-up

The system installed in Meltemi allows the DGs as well the household to negotiate in order to decide next sequence of actions. The system called MAGIC (Multi-Agent Intelligent Control) is a Java based software that implements the intelligent agents [4].

A critical component is the Intelligent Load Controller (depicted in Figure 4), which is based on an embedded processor that runs Linux, and monitors the status of a power line, and takes voltage, current and frequency measurements. It is designed for indoor installation and is equipped with a display in order to present directly messages to the consumer. Finally it is expandable with several serial and a USB port and has the ability not only to control but also to monitor several in-house appliances. The residents have online access to information about the status of the system, consumption and cost not only at the display on the controller but also through a web portal. Being informed is also critical part of the system since the residents will accept autonomous energy management systems only when they can see the realized energy savings and associated cost benefits.

Figure 4: The intelligent load controller used by the MAGIC system in field test C.

Preliminary Results and Lessons Learned

Several lessons have been learned from the installation within field test C. The major lesson is that it is important for the resident to have the only data in order to realize the consumption and the behaviour of certain devices. Next the market prices are also an important factor. Since currently in Greece they are quite low, the consumers will not pay attention to the energy efficiency gains by such systems. Regarding the critical situations, the system provided correct response to the various events, however the total number of houses participating should be increased in order to have better validation of results. Thus some large scale simulations will take place in order to evaluate the algorithms considering the behaviour of the system in the real test site.

CONCLUSION

Within the SmartHouse/SmartGrid project, a novel smart grid ICT-based approach, based on Smart Houses interacting with Smart Grids is being defined, implemented and field trialed. Its principal guiding directions stem from the innovative approach based on (i) end-user feedback, (ii) automated decentralized control of distributed generation and demand response and (iii) control for grid stability and islanding operation. In the three field tests we have carried out in three countries, we had the chance to acquire valuable feedback during the installation processes as well as evaluate concepts envisioned by the future smart grid. We have presented here initial experiences in each field trial which validate parts of the adopted technologies and approaches. In detail we have experimented with:

- Automatic aggregated control of end-user systems combined with testing of information exchange with enterprise systems using high-volume data traffic.
- Operation of a cluster of smart houses in order to improve energy efficiency, energy supply cost and grid operation.
- Reaction to critical situations of a cluster of smart houses to enhance security of supply.

The initial results are promising; however they have brought to light also several issues which need to be adequately tackled in order to have wide-spread adoption of the smart grid and fulfilment of its promise.

ACKNOWLEDGMENTS

This work was partly funded by the EU project SmartHouse/SmartGrid (www.smarthouse-smartgrid.eu). We wish to thank everyone that contributed to the project and its field trials, most notably: Sjaak Kaandorp, Pamela Macdougall, Gerben Venekamp, Barbara Dörsam, Andreas Kiessling, Britta Buchholz, Dejan Ilic, Per Goncalves Da Silva, Eleanna Hatzoplaki, and George Katsaros. Further, we thank the PowerMatchingCity partners of ECN: KEMA, Humiq and Essent.

REFERENCES

[1] D. Nestle, J. Ringelstein, 2008, “Bidirectional Energy Management Interfaces in distribution grid operation”, *3rd Int. Conf. on Integration of Renewable and Distributed Resources*.

[2] B. Roossien, et al., 2008, "Virtual Power Plant Field Experiment using 10 Micro-CHP Units at Consumer Premises", *CIRED SmartGrids Seminar‘08*, paper 86.

[3] N. Herrmann, *et al.*, 2008, "Washing with the Sun: Results of a Field Test for the Use of Locally Generated Renewable Electricity and Load Shifting in Households", *Int. J. of Distributed Energy Resources*, Vol. 4, Nr 4, 253-263.

[4] A. Dimeas, N. Hatziargyriou, 2007, "Agent based control of Virtual Power Plants", *Proc. of Intelligent System Applications to Power systems 2007*, ISAP.

[5] K. Kok, et al., 2005, PowerMatcher: multiagent control in the electricity infrastructure", *Proc. 4th conf. on Autonomous Agents and Multiagent Systems*, ACM Press, industry track vol., 75-82.

[6] S. Karnouskos, P. Goncalves da Silva and D. Ilic, 2011, “Assessment of High-performance Smart Metering for the Web Service Enabled Smart Grid”, ACM ICPE, 4-16 Mar 2011, Karlsruhe, Germany.

[7] K. Kok, et al., 2009, “Smart Houses for a Smart Grid”, CIRED 2009, Prague, Czech Republic, paper 751.