Monitoring and Control for Energy Efficiency in the Smart House

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Summary. The high heterogeneity in smart house infrastructures as well as in the smart grid poses several challenges when it comes into developing approaches for energy efficiency. Consequently, several monitoring and control approaches are underway, and although they share the common goal of optimizing energy usage, they are fundamentally different at design and operational level. Therefore, we consider of high importance to investigate if they can be integrated and, more importantly, how to provide common services to emerging enterprise applications that seek to hide the existing heterogeneity. We present here our motivation and efforts in bringing together the PowerMatcher, BEMI and the Magic system.

Key words: smart house, smart grid, web services, PowerMatcher, BEMI, Magic, software agents

1 Motivation

The existing electricity infrastructure is still primarily organized under the centralized approach where a few large power plants broadcast energy to the different consumers. However, in compliance with social and economic demands of our times, ongoing developments in the energy sector tend towards an increasing usage of alternative energy resources which are usually smaller and regionally dispersed. This leads to a very dynamic future energy network, where electricity will be produced in a distributed way, and customers are not only consumers, but also producers of energy (e.g. *prosumers*), and where bidirectional interaction between generators, consumers and other entities will be possible.

The research project SmartHouse/SmartGrid takes an innovative approach where the ICT framework 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 considers smart homes and buildings as proactive customers (prosumers) that negotiate and collaborate as an intelligent network in close interaction with their external environment [5]. The context is key here – the smart home and building environment includes a diverse number of units: neighboring local energy consumers (other smart 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 or small combined heat and power (CHP) plants.

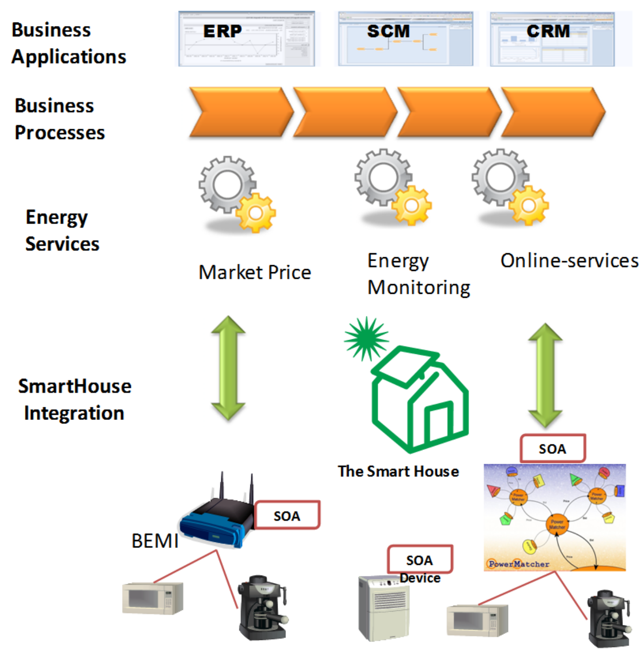

Fig. 1. Enterprise Integration of Smart Houses

As depicted in Figure 1, enterprise integration is expected to be the key issue for harvesting the benefits of the smart grid, empower new businesses and strategies, and enable market-driven approaches to flourish. Our approach is based on the following elements: (i) 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, (ii) aggregation software architecture based on agent technology for service delivery by clusters of smart houses to wholesale market parties and grid operators, (iii) usage of Service Oriented Architecture (SOA) [6] and strong bidirectional coupling with the enterprise systems for system-level coordination goals and handling of real-time tariff metering data.

Within the household, appliances and devices are integrated via some form of gateway or concentrator that connects to the smart grid. In our experiments we use three kinds of integration concepts, i.e. the *bi-directional energy management* *interface* (BEMI), the PowerMatcher and Magic system (details in section 3). What is also needed for realizing viable business cases with smart houses as part of the smart grid is the integration of in-house services with enterprise-level services. The last included typical business-to-customer services such as billing, but also other business-to-business services such as the interaction among different players such as the transmission system operator (TSO), distributed generation (DG) operator, energy retailer, wholesale market and others.

2 In-House Architecture Overview

The main goals for the design of the in-house architecture are to: (i) provide a software framework for applications in the area of energy management and energy efficiency at customers' sites in smart distribution grids, (ii) allow for access to devices and other hardware functionalities that are connected to the gateway via standardized data models or device service models, (iii) allow for automated registration of new devices based on standardized data models and device services, (iv) make the data provided from outside the in-house gateway that might be relevant to various applications (such as the price of electricity) accessible based on standardized data models, (v) define generic standard-based framework services for using these data models and device services, (vi) provide standardized services for functionality that will be needed for many applications: the user web interface, persistent storage of certain types of data and logging.

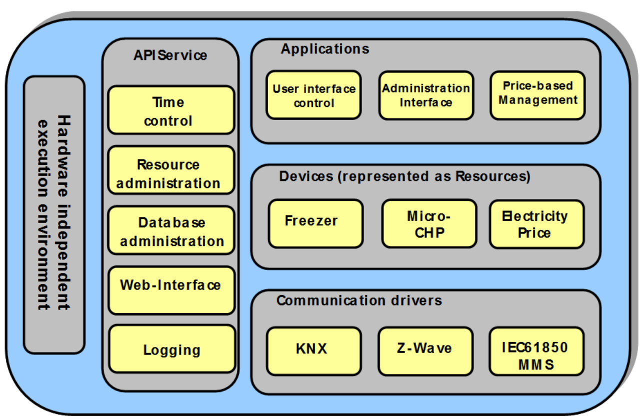

Fig. 2. Example: In-house framework

From these goals, several architectural elements of the framework have been identified and defined (depicted in Figure 2): *Application*: An application is a piece of software that is able to run in the environment of the in-house framework. In contrast to a communication system driver, it is not used to enable the physical connection to hardware. Applications represent certain use cases and should be specific to a use case.

Resource: A resource is a representation of states, parameters or other data generated outside the framework. So a resource can either represent a physical device, the parameters/state of a communication system or data transmitted to the system from a control station, such as a price profile.

Resource Type: A resource type is a model definition for resources. In order to enable automated device identification and plug&play, standardized resource types have to be used on all framework implementations. However, it shall be possible to add new resource types to a framework when standardized types are available. In an object oriented perspective, this is the class description of which the resources are instances.

Communication System: A communication system is able to connect the data representation of a resource with the actual physical device it represents or with the external data source (e.g. the control station delivering the price profile). In this way, the information of the physical connection of each resource is made transparent to the rest of the framework as it is processed solely by the communication system. Each connection links one data element of a resource to an address of a communication system. The addressing scheme of each communication system is specific to each communication system, of course.

API Service: The framework needs to offer several functionalities to the applications and communication systems. These services can be grouped into the administration of resources (Resource Administration), the administration of applications, the system time they are using and the way they are executed (Time Control), services for persistent storage of preferences data of applications and of data structures that are commonly needed by applications in the area of energy management and efficiency (Persistent Storage), access to a user interface and services for logging and evaluation of text log messages as well as of measurement data series. The API Service bundles all modules of services of the framework. Further services available to applications and communication systems can be provided by applications, but the services of the API Service can be expected on every framework implementation, thus being a base set for interoperability. The framework specification, thus, developed was not only described theoretically, but is also put into a reference implementation which will be tested in real field. Furthermore, in order to define and develop a standard for the in-house services described above, the Open Gateway for Energy Management Alliance (OGEMA – www.ogema-alliance.org) was kickstarted in September 2009. The scope of this alliance is to provide an open standard for a software framework for energy management in the building sector, including private buildings and households. This framework is to be run on a central building gateway which serves as interface between the smart house and the smart grid, integrating as many applications in the area of energy management and energy efficiency as possible. Standard and reference implementation will be made available for public download at the alliance's website.

The smart house will need to interact with numerous external entities, let it be alternative energy resources, marketplaces, enterprises, energy providers etc. In order to rapidly realize business processes, as well as efficiently take decisions, enterprise cockpits (Figure 3) are envisioned that will offer customized functionality depending on near real time data coming from a variety of sources including the smart houses.

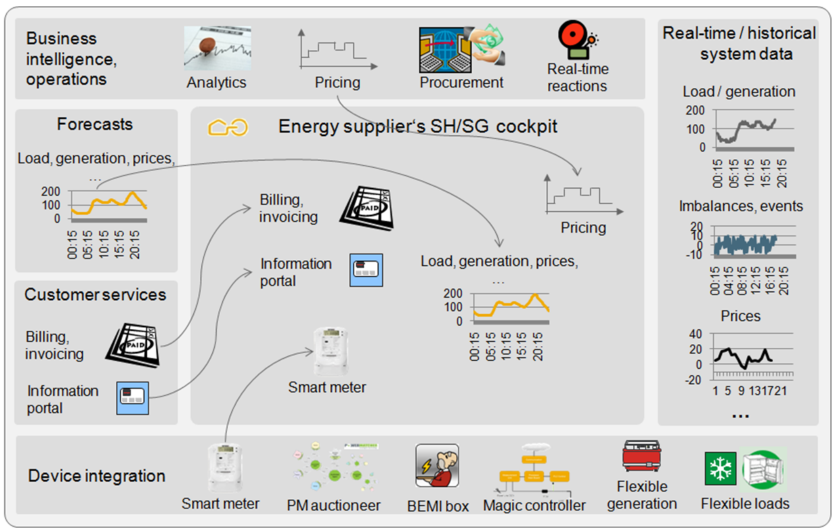

Fig. 3. Enterprise Cockpit for SmartHouse/SmartGrid Services

Any smart retailer or new energy service provider that wants to use the functionality of one or even more than one of the energy management technologies should be able to chose from existing services that are needed at the enterprise level. Through a service repository, the new enterprise should be able to integrate functionality into its system in order to realize its business case(s) which should be interoperable and functioning together. The de-facto standard for high-level communication today is via web services, which allows for flexible functionality integration without revealing details for the implementation. Therefore, the heterogeneity is hidden, while a common service-based interaction is empowering the creation of sophisticated applications. The SmartHouse/SmartGrid project is deeply investigating the possibility of using web services at least for the interaction of the smart house with other smart houses, and with entities in a smart grid.

Within the smart house, we have numerous protocols and even different technologies at the hardware communication layer. It is, however, a common belief that all of this heterogeneity will be hidden behind gateways and mediators, which will eventually allow the device to tap into an IP-based infrastructure, using Internet standards. Already today, the IP protocol is developed further to run in tiny and resource constrained devices (6LoWPAN), while with the IPv6 – and 6LoWPAN – any device will have its own IP address and be directly addressable. Due to IP penetration down to discrete device level, it is expected that devices will not only provide their information for monitoring to controlling entities, but will be able to dynamically discover nearby devices and collaborate with them. In this way, peer-to-peer interactions will emerge, which can be exploited by locally running applications that execute monitoring or controlling tasks. Devices in the smart house are and will remain highly heterogeneous, both in hardware and in software. As such, we need to find a way that this heterogeneity is abstracted, and yet communication (and collaboration) among them can be achieved. The development of middleware systems that act as the "glue" for device-to-business connectivity (and later also for device-to-device connectivity) is a viable approach.

3 Amalgamation of monitoring & control approaches

SmartHouse/SmartGrid does not have a common architecture in the classical notion, but rather advocates a framework that is an amalgamation of heterogeneous approaches that are "glued" together with SOA. This is a key part for enabling the future smart grid vision as we do not expect that a single architecture will prevail; rather several heterogeneous approaches will be applied but all of them will exchange information at higher level via common standardized approaches such as those enabled by web services (WS-* standards). We do not expect that a 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 follows three different architectures driven by common goals but fundamentally different in the way they approach the energy monitoring and management. Real world trials as depicted in Figure 4 will validate our efforts.

The first architecture is the PowerMatcher. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals. In the market-based optimization, the optimal solution is found by running an electronic equilibrium market and communicating the resulting market price back to the local control agents. The second architecture is the BEMI. It uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual loads and distributed energy resources (DER). In this approach, every decentralized market participant operates a BEMI interface which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs. In field test location B, this approach will be implemented as application using the OGEMA framework as a software basis. The third architecture is the Magic system which is based on a multi-agent system that enables the coordination of

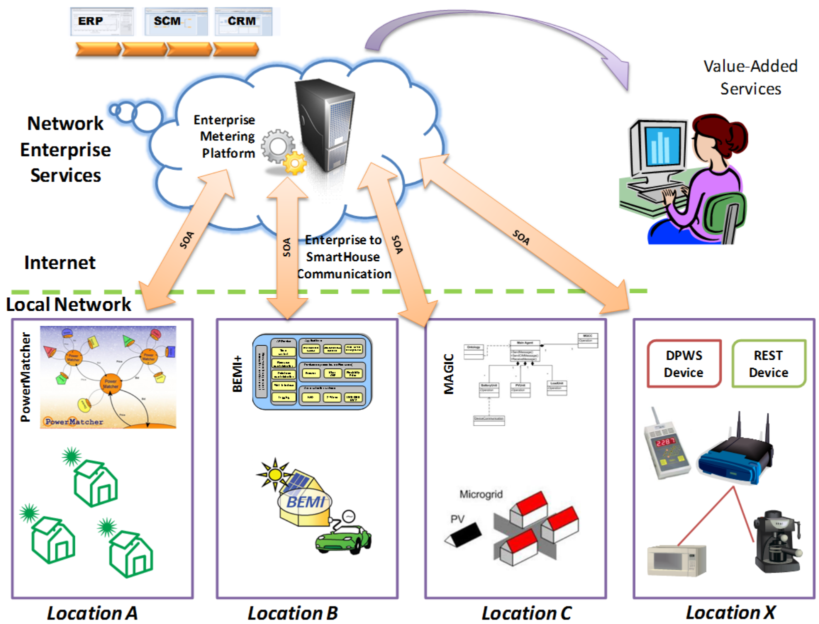

Fig. 4. Enterprise Integration in Trials: PowerMatcher, BEMI and Magic

the actors. The system provides an architecture that supports complex interactions between the agents based on agent communication language (ACL). The system is implemented upon the Java Agent Development Framework (JADE – jade.tilab.com) which is a FIPA (www.fipa.org) compliant platform. Finally, the description also provides part of the system organization, since the concept of coordination between the agents imports significant complexity to the system.

3.1 PowerMatcher

The PowerMatcher [2] concept uses agent technology that allows software agents, representing real-world entities, to interact with each other to perform a task or reach a certain goal. The agents are organized into a logical tree. The root of this tree is formed by the auctioneer agent that handles the price forming process. This price is based on the demand and supply functions that are issued by the leafs of the tree, the local device agents and, occasionally, by an objective agent. Concentrator agents can be added to the structure as tree nodes. The PowerMatcher concept is developed as a market based concept for coordination of supply and demand of electricity in networks with a high share of distributed generation. In this concept, a large number of agents are competitively negotiating and trading on an electronic market with the purpose to optimally achieve their local control action goals.

PowerMatcher is concerned with optimally using the possibilities of electricity producing and consuming devices to alter their operation in order to increase the over-all match between electricity generation and consumption. In the PowerMatcher concept, each device is represented by an agent which tries to operate the process associated with the device in an economically optimal way. The agents mediate the electricity consumed or produced by the devices by using an electronic exchange market. The electronic market is implemented in a distributed manner via a hyper-linked structure of so-called PowerMatchers. A PowerMatcher concentrator aggregates the demand and supply of the components directly connected to it and passes it on to its higher level controlling component, either another concentrator or an auctioneer. Different types of devices can act as related consumers and producers. The PowerMatcher auctioneer receives the aggregated demand and supply for the whole and determines from it the equilibrium price, which is communicated back to the concentrators and from there on to the agents. From the market price and their own bid function, each agent can determine the power allocated to its device. An auctioneer or concentrator cannot tell whether the devices connected to it are agents or other concentrators, since the communication interfaces of these components are equal. This makes the concept less privacy sensitive, while it is greatly scalable to include large numbers of device nodes.

3.2 BEMI

The BEMI [4] uses an energy management approach that is organized in a decentralized way and avoids a central control of the individual distributed energy resources (DER) like electric loads, generators and storage devices. Local optimization decisions are made through the customers themselves (or automatically by appropriate devices acting on the customer's behalf), who can act as consumers and/or producers of electric energy. In this approach, every decentralized market participant operates a BEMI, which optimizes the local power consumption and generation automatically, depending on local as well as central information like e.g. variable tariffs. The optimization is carried out on the basis of locally available information, which differs from the approach of typical virtual power plant (VPP) implementations. Thus, the customer has access to all optimization relevant data by means of a man-machine interface and, if desired, can also influence the optimization himself.

Generally, the BEMI coordination algorithms can be divided into two domains: Algorithms that are executed at the customer site by the customer grid interface (BEMI) and algorithms executed at the aggregation level usually in the domain of an energy provider or the DSO. The algorithms at the customer's site must react on the price profile given by a higher-order element named Pool-BEMI, typically situated at the energy provider. However, these algorithms also must take into account the processes and the parameters of the devices installed as well as customer preferences. The algorithms on the customer site shall be designed in a way that the energy cost for the customer gets minimized under the constraints defined by the customer. Energy provider and DSO thus need their own algorithms to ensure that they are also able to benefit from the management. The energy provider needs to fulfill the balancing schedule registered for a certain day, which means that the customers shall ideally consume or generate exactly as much energy per balancing interval as acquired from/sold to various sources. When calculating prices for customers also the customer contracts have to be fulfilled. The DSO has to make sure voltage level and line loads are maintained and might have to react to emergency situations. Whereas the energy provider usually defines the price profiles day-ahead like the existing energy exchange markets, the DSO has to react much more quickly. In order to enable this, using adaptations to the prices previously announced to the customers can be applied. Since this but influences the energy provider's business, DSO and energy provider have to agree on mechanisms how to use this possibility. A very straight forward and liberalized market oriented approach to this is the introduction of new distribution grid services offered by the energy provider to the DSO.

3.3 Magic

The Magic [1] is a multi-agent system (MAS) and its control approach supports several aspects of DG and controllable loads operation. This control approach also focuses on a concept called microgrid. This is a new type of power system which consists of small modular DG in the low-voltage (LV) grid. This control scheme introduces the idea that all the main decisions should be taken locally, being though in coordination with the other actors. The ability of coordination implies the usage of a high level language from the actors and consists of two main parts. The first part is that although the decision is local, it has to take into account the conversation or the negotiation between the actors. The second part is that a certain degree of high level coordination or monitoring is inevitable.

In a microgrid, each agent controls one unit of the system, for example a battery bank, a wind turbine or a controllable load. In the first step, the MAS, after negotiating with the energy supply companies (ESCo), receives a schedule for power production and power consumption that also includes prices. The negotiation and the decisions regarding the participation of the microgrid in the market belong to the higher level of control which constitutes the team behavior. The agents decide how to realize the schedule. Two schedules are created, one for production and one for consumption. The production schedule includes only the DG units and the consumption schedule only the controllable loads. Focusing on the production schedule, the DG units decide on how to share fairly the requested production. After the negotiation, each DG has a separate schedule and the control process moves to the lowest level, i.e. is the local level.In the local level, every DG unit accomplishes its schedule taking into account its special characteristics and status.

4 Conclusions

The infrastructure that will exist on the future smart house is expected to be highly heterogeneous. However, it seems that at some level all devices – either by themselves or via gateways – will be able to communicate over the Internet protocol and participate in bidirectional collaboration with other devices and enterprise services. Similarly, multiple concepts for monitoring and controlling the smart houses and the smart grid will emerge, with different optimization and control algorithms. It is therefore imperative not to focus on a single one-size-fits all approach, but rather also prove that an amalgamation of existing approaches can be done. The SmartHouse/SmartGrid project can be seen as first step on developing mechanisms for "gluing" different monitoring and control approaches as well as empowering the next generation enterprise services and applications. This is done by using web services and open standards and is applied to the PowerMatcher, BEMI and Magic systems.

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References

[1] A. Dimeas and N. Hatziargyriou. A multi-agent system for microgrids. In *3rd Hellenic Conference on Artificial Intelligence (SETN), 5-8 May 2004, Samos, Greece*, pages 447–455, 2004.
[2] J. K. Kok, C. J. Warmer, and I. G. Kamphuis. Powermatcher: multiagent control in the electricity infrastructure. In *AAMAS Industrial Applications*, pages 75–82, 2005.
[3] K. Kok, S. Karnouskos, D. Nestle, A. Dimeas, A. Weidlich, C. Warmer, P. Strauss, B. Buchholz, S. Drenkard, N. Hatziargyriou, and V. Lioliou. Smart Houses for a Smart Grid. In *CIRED 20th International Conference on Electricity Distribution, Prague, Czech Republic*, pages 1–4, June 8–11, 2009.
[4] J. Ringelstein and D. Nestle. Bidirectional energy management interfaces in distribution grid operation. In *3rd International Conference on Integration of Renewable and Distributed Resources, 10-12 December, 2008, Nice, France*, Dec. 2008.
[5] SmartGrids European Technology Platform. Smartgrids: Strategic deployment document for europe's electricity networks of the future, Apr. 2010. URL `http://www.smartgrids.eu/documents/SmartGrids_SDD_FINAL_APRIL2010.pdf`.
[6] C. Warmer, K. Kok, S. Karnouskos, A. Weidlich, D. Nestle, P. Selzam, J. Ringelstein, A. Dimeas, and S. Drenkard. Web services for integration of smart houses in the smart grid. In *Grid-Interop - The road to an interoperable grid, Denver, Colorado, USA*, 17-19 November 2009.