SMART HOUSES FOR A SMART GRID

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ABSTRACT

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. The architecture of such distributed system landscapes must be designed and validated, standards need to be created and widely supported, and comprehensive, reliable IT applications will need to be implemented. The collaboration between a smart house and a smart grid is a promising approach which, with the help of ICT can fully unleash the capabilities of the smart electricity network.

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 distribution system treats home and working environments as consisting of isolated and passive individual 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.

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.

Within the European Commission co-funded research project SmartHouse/SmartGrid (www.smarthouse-smartgrid.eu), a consortium of leading parties in ICT for energy takes a fundamentally different and innovative approach. 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 (see 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 context is key here: the smart home and building environment includes 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 (environmentally friendly energy resources such as solar and (micro)CHP etc.)

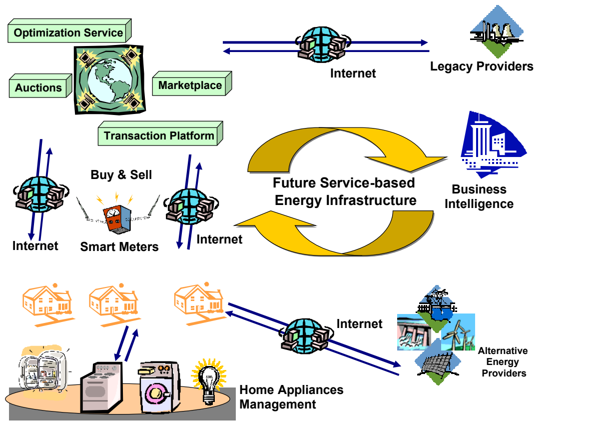

Figure 1: Service-based ecosystem based on Smart Houses and Smart Grids

The architecture 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 [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 strong bidirectional coupling with the enterprise systems for system-level coordination goals and handling of real-time tariff metering data. [6].

In this paper we introduce the core functionalities of this architecture. We do this by describing the three technical measures and the eight functional scenarios at which the architecture targets. These scenarios form the main functionalities that, together, are required in the common ICT architecture. Further, we discuss the expected impact of these innovations on the system-wide energy efficiency and the efficiency of distribution grid operations.

ICT ARCHITECTURE FUNCTIONALITIES

Aggregation of Houses as Intelligently Networked Collaborations

SmartHouse/SmartGrid concepts will exploit the potential that is created when homes, offices and commercial buildings are treated as intelligently networked collaborations. The SmartHouses will be able to communicate, interact and negotiate with both customers and energy devices in the local grid. As a result, the electricity system can be operated more efficiently because consumption will be better predicted and adapted to the available energy supply, even when the proportion of variable renewable generation is high. A commercial aggregator could exercise the task of jointly coordinating the energy use of the SmartHouses or commercial consumers that have a contract with it and additionally deliver services to grid management performed by the network operators.

Technical Measures

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

1. **End User Feedback:** Aims at an interface to the end user in order to give feedback on his/her energy behaviour and on the availability of (local) clean electricity.
2. **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).
3. **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: (1) the capability to run local power networks in islanded mode and (2) reaction of end-user systems to critical situations in the grid.

Functional Scenarios

For the functional scope of the SmartHouse/SmartGrid architecture, eight functional scenarios or business cases have been defined. A short description of each case is provided in the following subsections. Although described separately, these are all functionalities that need to be supported by the common ICT architecture.

Variable-Tariff-Based Load and Generation Shifting

The key idea of this business case is a variable price profile given to the customer day ahead before the delivery by a retailer. This profile is considered fixed after transmission to the customer and, as such, the customer can rely on it. The price profile will look different for each day, reflecting market conditions that vary from day to day. These variations will likely further increase with expanding generation from fluctuating sources like wind power and photovoltaics.

Generally, this concept allows for integration of loads as well as of generation units at the customer site as it is up to the customer which devices are allowed to be managed according to the variable tariff. To enable in-home energy management, a suitable domotic system is required together with an automatic home management device coupled to an intelligent meter.

Energy Usage Monitoring and Feedback

In the "Action Plan for Energy Efficiency", the European Commission estimates the EU-wide energy saving potential of households at approx. 27% [7]. As one important measure for realizing this potential, the action plan states that awareness must be increased in order to stimulate end-customer behavioural changes. A timely display of energy consumption is expected to have positive effects on energy savings. Personalized and well targeted advice on how to save energy can further help exploit the savings potential.

A portal or display that combines information about present and past consumption, comparisons to average consumption patterns, and precise suggestions how to further lower consumption, which are tailored personally to the customer, is expected to be the most effective way of realizing the targeted increase in households' energy efficiency.

Real-time Portfolio Imbalance Reduction

This business case is rooted in the balancing mechanism as used by TSOs throughout the world. In this context, a wholesale-market participant, that is responsible for a balanced energy volume position, is called a Balance Responsible Party (BRP). These parties have an obligation to plan or forecast the production and consumption in their portfolio, as well as notify this plan to the TSO. Deviations of these plans may cause (up-ward or down-ward) regulation actions by the TSO. The TSO settles the costs for the used reserve and emergency capacity with those BRPs that had deviations from their energy programs. On average this results in costs for the BRP referred to as *imbalance costs*.

This business case scenario focuses on the balancing actions by a BRP in the near-real time (i.e. at the actual moment of delivery). Traditionally, these real-time balancing actions are performed by power plants within the BRP's portfolio. The key idea of this business case is the utilization of real-time flexibility of end-user customers to balance the BRP portfolio. The BRP aggregates its contracted flexible distributed generation and responsive loads in one or more *virtual power plants* (VPPs), which perform the real-time balancing actions.

Offering (secondary) Reserve Capacity to the TSO
Taking the previous business case scenario one step further, the BRP uses these VPPs to, additionally, bid actively into the reserve capacity markets.

Distribution System Congestion Management
This business case is aimed at the deferral of grid reinforcements and enhancement of network utilization to improve the quality of supply in areas with restricted capacity in lines and transformers. The DSO avoids infrastructural investments and optimizes the use of existing assets by active management using services delivered by smart houses. By coordinated use of these services, end-customer loads can be shifted away from periods at which congestion occurs and simultaneousness of local supply and demand can be improved.

Distribution Grid Cell Islanding in Case of Higher-System Instability
The main principle of this business case is to allow the operation of a grid cell in island mode in case of higher-system instability in a market environment. The scenario has two main steps, the first occurring before a possible instability and involves keeping a load shedding schedule up-to-date. The second step is the steady islanded operation.
The transition to the island mode is automatic and neither end users nor the aggregator interferes with it. The ICT system manages the energy within the island grid and it is considered that all nodes within the islanded grid will participate in the system.

Black-Start Support from Smart Houses
The most important concept of this business case is to support the black start operation of the main grid. It is assumed that after the blackout the local grid is also out of operation. The main goal is to start up quickly in island mode and then to reconnect with the upstream network in order to provide energy to the system.

Integration of Forecasting Techniques
The volatility of the production level of distributed generators, like renewables and CHP, makes forecasting a necessary tool for market participation. The market actor with the lowest forecasting error will have the most efficient market participation. Moreover, the usage of intelligent management tools for handling the information about the uncertainties of large-scale wind generation will improve the system-wide operational costs, fuel and CO_2 savings. The ICT architecture under development must interact with these forecasting tools and additionally ensure accurate data collection for these tools.

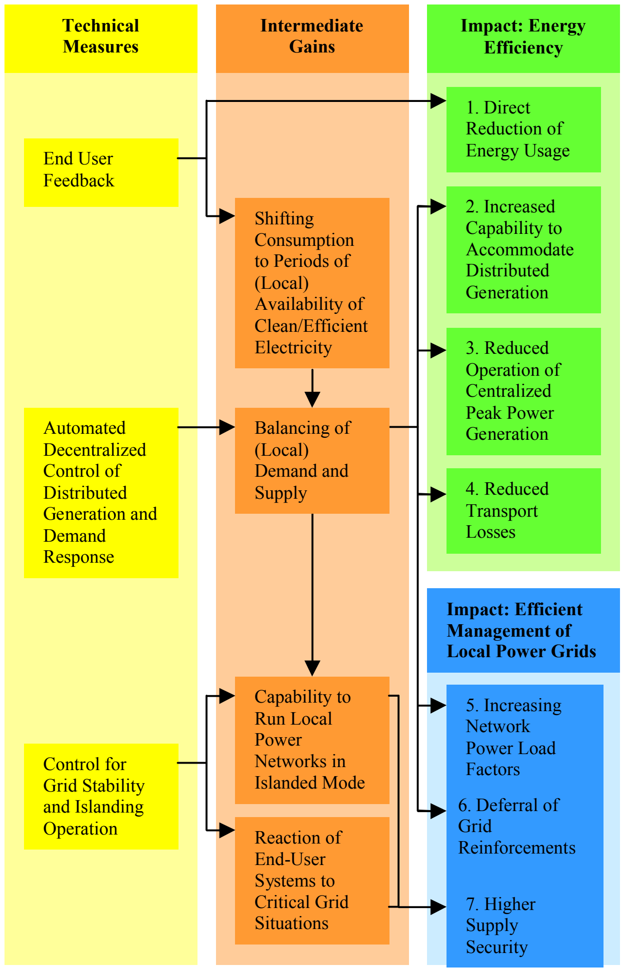

Figure 2: How technical measures in Smart Houses for Smart Grids impact energy efficiency and efficient network management.

EXPECTED IMPACT

The expected impact of the architecture under development can be broken down in two parts:

- Energy efficiency, including avoided fossil fuel usage due to increased levels of renewable generation.
- Efficient management of local power grids

Figure 2 describes the relation between the technical measures as described earlier and seven impact categories. The categories themselves are described below:

1. **Direct Reduction of Energy Usage** due to end-user feedback. This type of feedback is part of the European End-Use Energy Efficiency and Energy Services Directive [7] and has an expected energy efficiency effect of 10 to 15%. Another type of feedback addressed encourages the end-user to shift part of their electricity consumption towards periods

when (locally) produced clean electricity is highly available. Experiences with small-scale tests show a potential for this type of feedback [3].

2. **Increased Capability to Accommodate Distributed Generation.** Experiences in a number of places (e.g. in Denmark) show that grid operation encounters problems when the share of generation capacity outside the reach of centralized control grows beyond a certain level (typically 10%). By increasing the demand/supply match in local networks, the share of local production may grow well beyond this level without grid stability problems, expectedly, to 100% of local consumption (energy neutral homes, energy neural estates). Thus, balancing local demand and supply increases the accommodation capability for renewables and CHPs.
3. **Reduced Operation of Centralized Peak Power Generation.** A better local balance of demand and supply in distribution networks will result in a smoother profile of energy exchanged with transmission networks. This will decrease the use of centralized peak-power generators. The efficiency enhancement of this is high as peak-power generation is generally inefficient and environmental unfriendly.
4. **Reduced Transport Losses:** a better local balance of demand and supply in distribution networks will also reduce the amount of energy exchanged with higher network parts relative to the local consumption. This will result in less energy transport and, thus, less transport loss per consumed kWh.
5. **Increasing Network Power Load Factors:** A better balance will flatten the power duration curve of power networks, resulting in a more efficient usage of network assets.
6. **Deferral of Grid Reinforcements:** Demand and supply balancing mechanisms can be used by network operators for congestion management.
7. **Higher Security of Supply for the End User:** Capability of local networks to run in islanded mode and the possibility to let end-user systems respond to critical situations enhance the security of supply in distribution networks.

CONCLUSION AND OUTLOOK

Within the SmartHouse/SmartGrid project, a novel smart grid ICT architecture, based on Smart Houses interacting with Smart Grids is being defined. It takes a fundamentally different, innovative approach based on (1) end-user feedback, (2) automated decentralized control of distributed generation and demand response and (3) control for grid stability and islanding operation. Implementation of the ICT measures is expected to have a high impact, throughout the full electricity value chain, on energy efficiency, sustainability and grid management efficiency.

This new technology will be field tested in three different countries. Each field trial will deliver proof of concept of a specific aspect of the new technology:

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

On the basis of the results and experiences from these field experiments, the project will define a roadmap focused toward a mass-market application of the SmartHouse/SmartGrid technology.

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