ACTIVE HOUSE DEPLOYMENT ARCHITECTURE FOR RESIDENTIAL ELECTRICITY CUSTOMERS' ACTIVE INTERACTION WITH THE SMART GRID

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ABSTRACT

Active House is a concept developed by a large collaboration of actors from the automation, power, telecom, white goods industry and research institutes. The frame is the Stockholm City's Royal Seaport city development area which focuses on sustainable development and extensive CO_2 reductions. The residential building is called an "Active House" since it has active interaction between the electricity consumer and the utility. The active interaction aims at reducing utilization of electricity production with high CO_2 emissions and includes customer-controlled post-shift and reduction of the consumer's electricity loads and local electricity production.

INTRODUCTION

EU's aim is a 20% cut in greenhouse gas emissions, a 20% increase in energy efficiency and to have 20% of energy from renewable sources - all by 2020. As a contribution to this goal, the Stockholm Royal Seaport Smart Grid project was formed in 2010 with targeted installations in 2013. The goals of the Stockholm Royal Seaport Smart Grid project are several: (1) increased electricity production from renewable sources, (2) improved grid infrastructure in order to handle introduction of small-scale production and the electric cars; (3) decreased and shifted electricity consumption by including the domestic electric loads in the electric power system; and (4) improved feedback of both electricity consumption and production to the residential electricity customers. The Active House was developed as a concept to meet these project goals, and includes active demand response interaction between the residential electricity consumer's home automation equipment and the utility. Contrary to a centralized system, where the utility sends direct demand and response control signals to customer appliances, the Active House residential demand response system receives utility information about the electricity generation mix and proposes a cost and/or CO_2 minimizing load scheduling based on the information. The customer is allowed to manually override the proposed scheduling of loads if needed.

In this paper we present the Active House residential demand response system and its integration in the smart grid. The Active House deployment architecture, which has been designed taking into account triple-bottom-line sustainability requirements and is based on open standards, is presented. We demonstrate the proof-of-concept by referring to the results of an industrial demonstrator that was exhibited at the ELFACK fair in 2011 [8].

STOCKHOLM ROYAL SEAPORT SUSTAINABILITY REQUIREMENTS

The Stockholm city triple-bottom-line (social, environmental, and economical) sustainability requirements on SRS are specified in [1]. It is expected that each partner is responsible for inspection and control to ensure that the requirements are met during the entire process of the SRS urban district development. To complement the inspection and control enforced by each of the partners, Stockholm City is developing a sustainable development follow-up model together with KTH. The follow-up model will be fed by data from households, buildings and the city area during the building phase as well as during the operational phase to document that the SRS requirements are met.

Main targets are for CO_2 emission below 1.5 ton per person in the year 2020 (today average 4.5 ton) and for the area to be fossil free in the year 2030. In order to contribute to these targets a common understanding of the SRS sustainability requirements has been established for the Active House:

- The energy consumption in residential buildings shall not exceed 55kWh/m2/year whereof electricity consumption maximum 15kWh/m2/year.

Each residential building shall generate at least 30% of its consumed building electricity based on local renewable energy; potential excess electricity will be delivered to the electricity net by contract with the electricity supplier

- Individual measurement of hot water and household electricity shall be made in each apartment and the resident shall be able to see and control their energy consumption
- Each apartment shall be charged for its individual electricity consumption
- It shall be possible for the residents to achieve a household energy consumption of less than 20kWh/m2/year
- The operation of installed systems shall be optimized in collaboration with the residents
- A parking space of 0,5 space/apartment shall be prepared for EV charging with EV charging units based on environmental friendly classified electricity or locally generated renewable electricity
- Residential buildings and offices shall be equipped with user friendly systems for individual measurement, reading, and control of their consumption of energy and water and the waste generation where cost and pricing shall be visualized in a clear and pedagogical way

SUSTAINABLE DEVELOPMENT MODEL

Here we discuss the main assumptions and simulation of the electricity consumption's CO_2 emission impact.
In the early project phase we formulated the following assumptions:

- If CO_2 (t1) > CO_2 (t2) then we decrease CO_2 emissions by the electricity consumption shift from time-point t_1 to t_2.
- If consumer's electricity cost(t1) > electricity cost(t2) then we decrease consumer electricity cost by the electricity consumption shift from time-point t_1 to t_2
- If electricity peaks are reduced, the net owner can reduce necessary grid capacity by the electricity consumption shift from time-point t_1 to t_2

The dynamic CO_2 intensity, CO_2 (t), is the amount of CO_2 emissions per unit produced electricity, here measured as gCO_2eq/kWh. We will see different levels and patterns in the dynamic CO_2 intensity depending on the electricity generation mix composition and how this composition changes. Hours when high emitting electricity generation technology has been utilized will have a higher CO_2 intensity than those hours when e.g. wind or hydro electricity generation technology with low CO_2 emission has been utilized.

Frame for Environmental Impact Reduction

We performed dynamic CO_2 intensity simulations, using Swedish electricity generation mix statistics on hourly basis, and collected information on hourly electricity consumption patterns. Using the combination of the two, we saw that there is a CO_2 reduction potential in shifting electric loads to hours of low emitting electricity generation. Shifting doesn't necessarily mean reducing, but a reduction of electricity consumption during hours of high emitting electricity generation will of course contribute to CO_2 emission savings. However, in the simulations we saw that the CO_2 intensity for the Swedish electricity generation mix was not correlated with hours of peak load. The reason is that Sweden uses low emitting hydro-power and nuclear power as base power and hydro power as load following power. During peaks, the hydro power share in the Swedish generation mix increases and contributes to a lowered CO_2 intensity. The very low Swedish CO_2 intensity is sensitive to import from countries with high emitting electricity generation technologies such as coal-fired production.

Incentives for Environmental Impact Reduction

The dynamic CO_2 intensity should be calculated for a specific supplier as part of the Electricity Disclosure that is a requirement implemented in the revised Electricity Market Directive 2003/54/EC [2]. The correlation between the hourly electricity price and the hourly CO_2 intensity will differ between the suppliers depending on load following technology, electricity generation mixes and electricity pricing. Three types of incentives will be used: informative incentives (use of the dedicated display to present information about economic impact and environmental impact of energy used); administrative incentives (IMD directives); and economic incentives (agreements to change usage patterns based on economic rewards). How households will handle hours with high electricity prices and low CO_2 emissions remains to be investigated.

ACTIVE HOUSE DEPLOYMENT ARCHITECTURE IN THE SMART GRID

The Active House architecture is based on open standards and influenced by different Smart Grid initiatives, e.g. NIST Smart Grid interoperability Group [3], EU Task Force on Smart grid [4], and IEC Strategic Group on Smart Grid [5]. We looked to the standards environment as a basis in order to ensure that the deployment model is future proof and with the ability to integrate solutions of different parties in an optimal way; meaning that the component architecture and interfaces should conform to standards to ensure interoperability with both existing and future evolving changes to installations and communications infrastructure. Open standards are required to achieve interoperability between different vendor products and solutions and open standards-based communications is a prerequisite for the intelligence in the Smart Grid to work; the communications infrastructure must be based on standardized communications protocol stacks.
The sustainability requirements of the Stockholm City also have a strong impact on the designed architecture. As explained above, the project aims to support a demand response based load shaving/shifting program; the deployment architecture must therefore be designed to support and implement such a program. As there was resistance to direct control programs in Sweden the project has also chosen a decentralized model which allows residents to control which loads to shift and schedule these voluntarily (e.g. based on price incentives).
The AH system architecture enables demand response integration of home/building automation system, EVs, smart appliances, Solar Photovoltaic (PV) cells, and local energy storage. Further, the Active House architecture supports visualization of energy consumption related information.
A deployment view is given in Figure 1. The central component in each apartment is the Energy Services Interface (ESI). The ESI has outbound communication towards the smart grid service providers, e.g., utility. The ESI has inbound communication with the home automation system, smart appliances, local energy production in the form of a solar PV system, charging outlets for Electric Vehicles (EVs), and energy meters. Moreover, the ESI hosts logic for coordinated control of household consumption and generation. Many of the household consuming functions have a built-in flexibility, such as the washing machine and the EV charging can e.g. be started when the supply of renewable energy is high. In this deployment, the communications interfaces towards the demand response

system and between the household level routers and the building level router are transported over a public, IP-based communications interface. The communications infrastructure for the data and signalling exchanges with the AMI system will depend on the communications module to be deployed along with the meters and the meter gateway, and may be transported over a public IP-communications network or a private network.

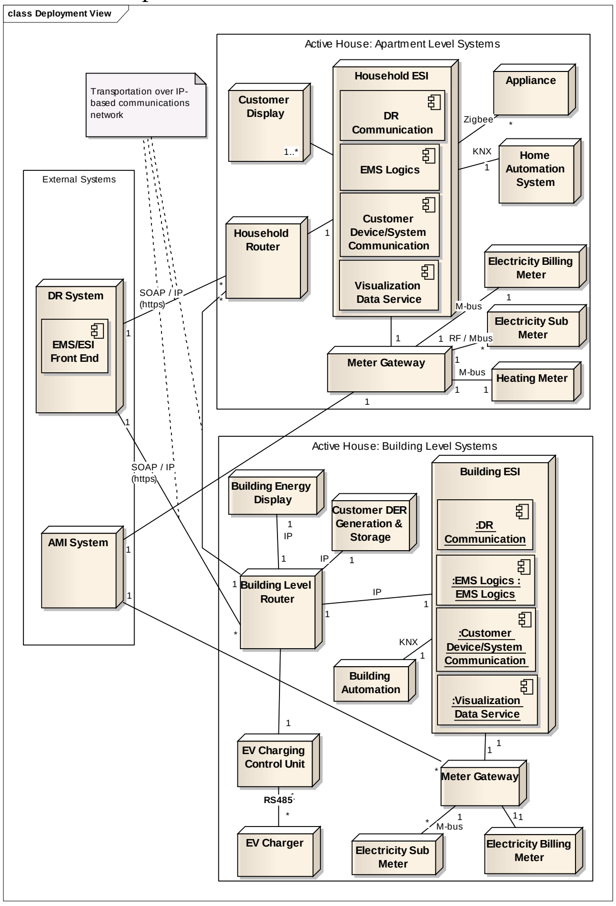

Figure 1 Active House deployment architecture

Home automation combined with demand response energy management for load shifting and peak shaving make it possible to increase energy conservation; the KNX standard is an important standard for integrating the customer premises into the grid, providing the means to automatically monitor and control devices in the home. Both OpenADR [7] and IEC 61968-9 are standards under development that are important for standardizing the DR communications.

The deployment architecture shown in Figure 1 depicts the deployment architecture that was designed during the pre-study phase of the SRS project, and this deployment architecture formed the basis for the ELFACK industrial demonstrator to be discussed in the next section.

ELFACK DEMONSTRATOR

The Active House industrial demonstrator has been developed to demonstrate residential demand response by incorporating home/building automation through a prototype of the demand response interface (the ESI) to the utility. The demonstrator also provides us with the means to evaluate the applicability of the architectural solution.

The demonstrator is composed of one visualization device, and number of different devices that are commonly used in the household. These devices include electrical outlets, (used for different purposes such as charging of mobile devices) programmable thermostats, lights, blinds, a washing machine, heating cables in the floor, as well as an Electric Vehicle (EV) charging unit. Each of these devices is connected in the home network using KNX technology [6]. The central device in this network is the ESI that is designed to receive electricity price signal and CO_2 emission information from the service provider. Based on this information, the ESI performs energy management of the household in terms of determining an optimal start time of the washing machine based on the electricity price information, CO_2 emission information and user preferences.

The actuators for each of the functionalities of home/building automation that the Active House industrial demonstrator demonstrates are shown in Figure 2, indicated by the letters assigned to them:

- Home / Away button (A)
- Controlled start of smart appliances (B)
- Water leakage warning system (C)
- Controlled start of EV charging (K)
- Controlled heating (D)
- Controlled outlets (E)
- Controlled ventilation (F)
- Controlled lights (G)
- Controlled blinds (H)
- Window open sensor (I)

The interactive display for visualization of the amount of energy consumed in the household and the possibility to interact and make changes to reduce consumption was implemented as shown in Figure 3. The energy management logic implemented interacts with the home automation and helps the resident to limit the energy consumption (e.g., by decreasing temperature for heating, decreasing ventilation, dimming lights, and setting certain outlets off) during times when the price/ CO_2 emissions are high. The figure shows a screen dump of the active visualization screen when a web-browser is connected to the ESI.

Using the demonstrator we have been able to validate the deployment architecture as a working solution for a residential demand response system. We have demonstrated home/building automation system control of household loads using the demand response signals: hourly electricity price and CO_2 intensity 24h forecasts. The control was demonstrated as automatic shifting of loads based on the demand response signals received by the ESI during the course of a day visualized for the user in real time on the display. The demonstrator was presented at ELFACK 2011 fair, where it was very well received. Based on the feedback provided at the fair, the project has continued extending the demonstrator to cover all parts of the Active House deployment architecture.

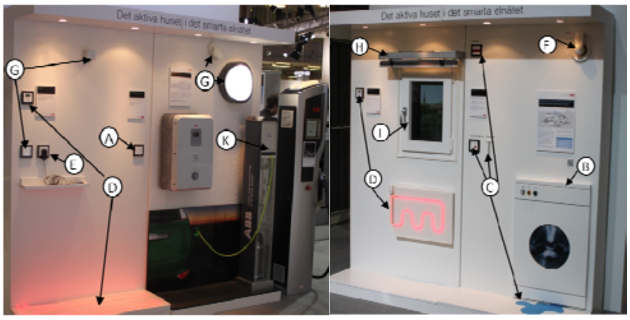

Figure 2 The ELFACK demonstrator installation (the two sides of the fair booth)

Likewise, work on the presented energy visualization concept continues and will also be included in the Active House deployment for the SRS project in 2013 and beyond.

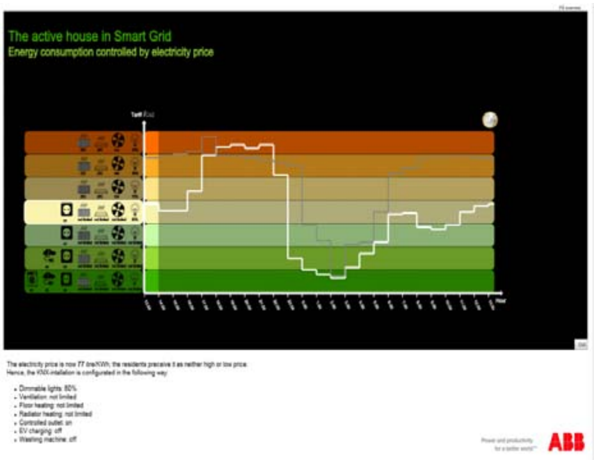

Figure 3 Visualization Display

CONCLUSION

In this paper we have presented the Stockholm Royal Seaport Active House deployment architecture describing how it has been derived based on open standards initiatives [3]-[5] to meet the triple-bottom-line sustainability requirements of Stockholm City [1]. Changing an existent part of the electricity distribution grid involves several stakeholders. Collaboration is possible, but requires both government requirements on changing the system and many lengthy discussions to find value for all in the new system solutions. Household incentives to participate are not mainly economical. The household also wishes to get better control over their electricity consumption and possibilities to use electricity more environmentally friendly. Active House will through information and technical systems increase the household's control over their electricity consumption and use the most environmentally friendly control as default control. The dynamic CO_2 emission model for a power system was developed to evaluate if the assumption that shifting electric loads from one time period to another and reducing loads when the electricity production has high CO_2 emissions would result in CO_2 emission savings, especially during peak load periods. Active House has added social value with the home automation system in terms of comfort, safety and ambient assisted living functions. The CO_2 emission and electricity cost saving potential are implemented as add-on functions to the home automation system's normal functions. However, when households are not the direct buying instance, as for apartments, the builders are the ones that need to be convinced about the benefits of residential demand response systems. This has proven to be rather challenging. The International Energy Agency (IEA) has in their report "World Energy Outlook 2012" presented energy efficiency, especially for buildings, as the key target for reducing Europe's CO_2 emission the coming years [9]. This might have an impact on regulations and funding incentives benefiting residential demand response systems.

Further work includes optimizing load shifting to maximize the reduction of CO_2 emissions. It also includes expanding the shift and reduction functions to include other energy kinds as heating and hot water.

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