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Managing energy Smart Homes according to energy prices: Analysis of a Building Energy Management System

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ABSTRACT

The Demand-Side-Load Management will change the way people behave. Different authors have proposed energy management algorithms for Smart Home that either integrates or not renewable energy. All these researches have the same general objective: minimizing the daily energy cost without affecting the comfort of occupants. This paper deals with the performance analysis of a Global Model Based Anticipative Building Energy Management System (GMBA-BEMS) managing household energy. This GMBA-BEMS is able to optimize a compromise between user comfort and energy cost taking into account occupant expectations and physical constraints like energy price and power limitations. To validate the GMBA-BEMS, the model of a building has been developed in MATLAB/Simulink. This work analyzes GMBA-BEMS application that manages appliances such as heating, washing machine and dishwasher from a grid point of view.

1. Introduction

Local energy production and consumption means in a Smart Home can be managed by a Building Energy Management System (BEMS). Advanced BEMS makes it possible to deploy new kinds of energy management strategies that may change the way of consuming and producing energy by supporting occupants to reach a better energy performance and comfort.

A Smart Home is a residential dwelling equipped with sensors and possibly actuators to collect data and send control according to occupants' activities and expectations [1,2]. Potential applications for Smart Homes are described in [3]. The goal of these applications is to improve home comfort, convenience, security and entertainment [3].

Thanks to this communication network, a load management mechanism has been proposed in [4]. Since then, several studies have been conducted in order to design an optimized electric BEMS able to determine the best energy assignment plan according to a given criteria. In [5], an analysis of the load management techniques is detailed. According to [6], Energy Management System contains methods that coordinate the activities of energy consumers and energy providers in order to best fit energy production capabilities with consumer needs. With such solutions, electricity can be reduced to support the grid.

During the last 2 years, many research projects focused on demand side management and loads control of domestic Smart Grid technologies for many reasons. First, energy use in buildings currently account for about 32% of global total final energy consumption in the world. In terms of primary energy consumption, buildings represent around 40% in most IEA (International Energy Agency) countries [7] and 65% of the total electric consumption in [8]. Buildings are also responsible for 36% of the EU CO2 emissions [7]. Not only Energy performance, but also load management in buildings is a key issue to achieve the EU Climate & Energy objectives, namely the reduction of a 20% of the Greenhouse gases emissions by 2020 and a 20% energy savings by 2020 [9].

These technologies may modify the domestic energy use (electricity and heat) and adjust the electricity consumption/production in dwellings [10,11]. These researches can be divided into two complementary categories: predictive energy management and real time control. This control uses prediction model in addition to measured data in order to forecast the optimum control strategy

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that will be implemented. Similar researches have been carried out on predictive controllers using stochastic models [12]. Both short-term (10–20 min) and long-term (days) prediction errors lay within acceptable ranges both in terms of temperature and humidity level.

The second category of research uses also the predictive control but it introduces real time control algorithms in order to give more benefits contrary to [13,14] which do not study the price prediction. Most of these researchers studied the real time electricity pricing environments to encourage users to adjust load peaks for two goals: reducing their electricity bill and reducing the Peak-to-Average Ratio (PAR) in load demand [15,16].

The BEMS are usually based on simple models because it is difficult to determine the parameters of detailed models that fits actual measurements. BEMS has to be "appropriate" to detailed models. The problem of the evaluation of the degree of "appropriation" and then the evaluation of the proposed solutions by the BEMS is rarely treated as a research problem. This work deals with an analysis of a Global Model Based Anticipative Building Energy Management System (GMBA-BEMS) managing household energy.

Most anticipative approaches of energy management problem focuses on specific appliances like electrical water heater in [16] and HVAC (heating, ventilation, and air conditioning) system in [15]. HVAC is the technology of indoor and vehicular environmental comfort. HVAC system design is a subdiscipline of mechanical engineering, based on the principles of thermodynamics, fluid mechanics, and heat transfer.

According to [17], the approach of GMBA-BEMS called G-homeTech used in this paper is general enough to handle a large set of electric appliances: electrical heater, washing machine, dishwasher, fridge, etc. It represents 80% of the total residential consumption [18].

The rest of this paper is organized as follows: The following section states the objective of the work. The solution proposed for the analysis of a BEMS is presented in Section 3. In Section 4, the settings and the problem solved by the GMBA-BEMS are detailed. Analysis of a GMBA-BEMS is presented in Section 5.

2. Paper objective

2.1. Problem statement

As detailed below, BEMS are based on simple models because it is difficult to determine the parameters of detailed models that fits actual measurements, BEMS has to be "appropriate" to details models: it requires *validation scenarios* and a *building simulator* connected to a BEMS.

Regarding the proposed *testbench*, the energy management strategy aims to minimize the household's electricity cost taking into account price signals from the grid by optimally scheduling the operation and energy consumption of each appliance according to user comfort expectations. As in [15], a time varying curve of electricity price is used. The household load management is based on price and consumption forecasts considering users' comfort to meet an optimization objective which compromises minimum payment and maximum comfort. Real time adjustments are then done according to real time electricity market prices actual interest. However, in this study, it is done according to the total available power: the PV production (according to solar radiation curves) and the power limitation (subscription), to the electricity market prices, and the power consumption of the other appliances (Fig. 1). Notes that PV is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. Photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material.

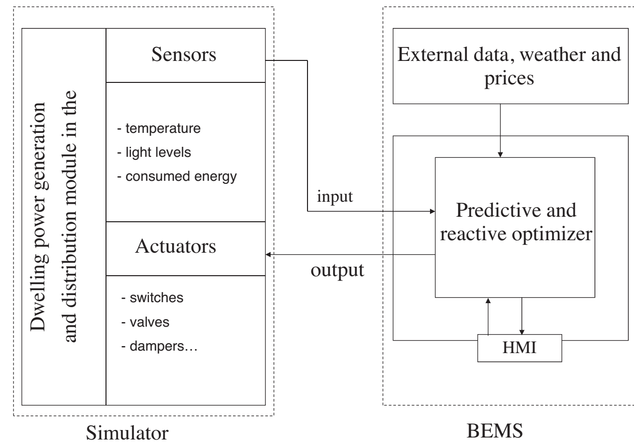

Fig. 1. Virtual co-simulation general schema for BEMS validation.

The validation testbench is not only concerned with the heating control such as in [19,20], but also with the electrical appliances making the problem more complex. It aims to introduce a real time energy management-decision based on both reactive and anticipative global algorithms [21] contrary to [22,23] where the authors use predictive control to anticipate a solution for heating systems. [17] and [24] detail the BEMS algorithm selected for the proposed analysis. The anticipative layer assigns energy references by taking into account predicted events. Concerning the reactive layer, it intervenes when the anticipative plan cannot be followed because of unforecasted events and it decides whether some appliances have to be switched ON or OFF.

On the other hand, to validate a BEMS, two parts must be presented: the *simulator* and *the energy management algorithms* (Fig. 2). In the BEMS, the multi-layers algorithms are in interaction with external data that comes from the weather, the energy marketer, the Human Machine Interface (HMI), and the real time simulator. The HMI can be used by the occupant to provide instructions to the BEMS.

Simulators replace a dwelling and its HVAC systems to simulate their response to the BEMS as described in [20]. They are used to improve product development, to train BEMS operators, to tune actuators, and to simulate faulty situations [25]. Then, The validation of a BEMS should be done through a simulator model. The simulation models includes in addition to the HVAC many electrical appliances such as lighting, flaps, washing machine, dishwasher and fridge.

Some simulators are presented in the literature. For example, the software "PME_Comfort" is used to simulate the thermal comfort of dwelling [26]. "Solene" [27], simulates the sunshine, light and radiation. "ESP-r" [28] and "FLOVENT" [29] simulate the movement of air in dwellings. In [30], there is a comparison between two environments for dynamic simulations of dwellings "CODYRUN" [31] and "TRNSYS" [32]. Because of the complexity of usage for such advanced tools, new more accessible simulation tools have been developed including "COMFIE/ PLEIADES" [33,34] and "EnergyPlus" [35,36] offering the ability to model dwelling and HVAC system.

SIMBAD [37] (SIMulator for Buildings And Devices) is one of the recently developed simulator that may easily take into account control systems in MATLAB/Simulink environment. It uses both the "TRNSYS" and "HVACSIM+" [38] simulation software. Johnson Controls and the National Institute of Standards and Technology (NIST) in the US have developed a low cost PC-based emulator [39]. The company is now using it for the purpose of testing new control products.