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A demand side management strategy based on forecasting of residential renewable sources: A smart home system in Turkey

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ABSTRACT

The existing electricity systems have been substantially designed to allow only centralized power generation and unidirectional power flow. Therefore, the objective of improving the conventional power systems with the capabilities of decentralized generation and advanced control has conflicted with the present power system infrastructure and thus a profound change has necessitated in the current power grids. To that end, the concept of smart grid has been introduced at the last decades in order to accomplish the modernization of the power grid while incorporating various capabilities such as advanced metering, monitoring and self-healing to the systems. Among the various advanced components in smart grid structure, "smart home" is of vital importance due to its handling difficulties caused by the stochastic behaviors of inhabitants. However, limited studies concerning the implementation of smart homes have so far been reported in the literature. Motivated by this need, this paper investigates an experimental smart home with various renewable energy sources and storage systems in terms of several aspects such as in-home energy management, appliances control and power flow. Furthermore, the study represents one of the very first attempts to evaluate the contribution of power forecasting of renewable energy sources on the performance of smart home concepts.

1. Introduction

The growing concern on environmental impacts of conventional energy sources and the finite life of fossil-based fuels has oriented the attention to the renewable energy sources. However, the penetration of such decentralized and intermittent energy sources with variable capacity to the current electrical power networks designed to generate and distribute electricity from a certain number of large central power stations has been emerging as a major problem. Therefore, in order to facilitate the cost-effective exploitation of the present renewable energy potential and provide the required flexibility to the electricity grid with the help of information and communication technologies, the smart grid concept has been introduced as a strong candidate solution at the last decades.

The smart grid concept can be defined as the next-generation electrical grid that utilizes advanced control and communication components in order to optimize the energy generation, distribution and consumption. Energy efficiency, power quality and system reliability can be enhanced by using multiple tools of smart grid such as advanced meters, two-way communications and intelligent control equipment. Furthermore, the smart grids have the potential of exploiting renewable sources as well as providing the required infrastructure for electric and hybrid vehicles. Due to the mentioned benefits, smart grids also play a vital role in reducing the emissions of greenhouse gases (carbon dioxide, methane and nitrous oxide).

In the literature, smart grids have been comprehensively investigated in terms of their structures, components and advantages [1–3]. In the studies, it is especially highlighted that the power flow in grids can be carried out more efficiently by obtaining and then evaluating the consumption profiles of houses. Accordingly, the studies have been focused on "smart homes" that can be deemed as one of the most important components of smart grids [4–6]. To that end, a smart home was established in a laboratory environment at Yildiz Technical University, Istanbul in order to give an insight into the performance of experimental results that could be rarely found in the literature. With the help of advanced metering and display technologies in the smart home developed, the user or the system itself is able to lower the energy consumption or postpone the energy intensive operations regarding the present electricity price by controlling the household electrical goods under the constraint of guaranteeing a certain comfort level. In the literature, it is indicated that 10–30% domestic energy consumption reduction can be accomplished by only providing the consumption profile of

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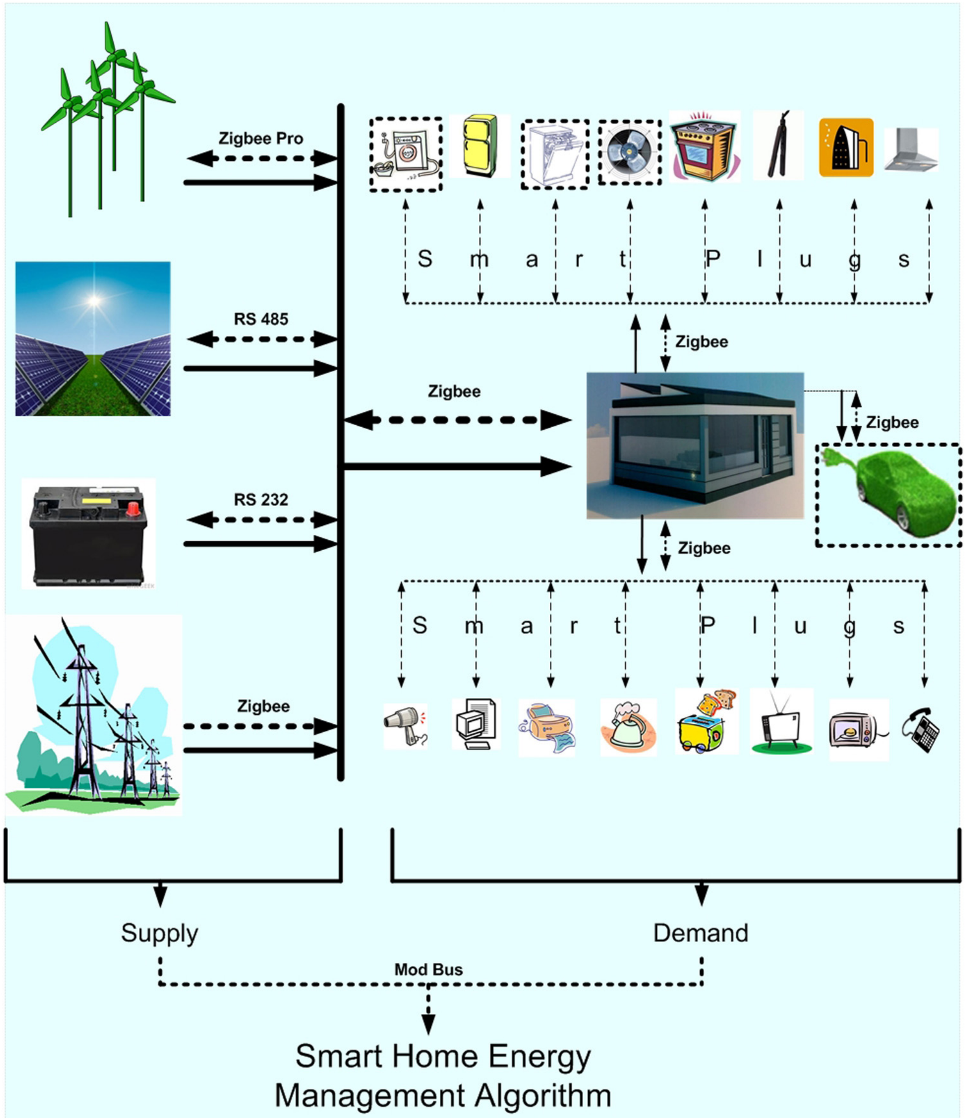

Fig. 1. General scheme of the smart home.

appliances to the consumers and accordingly helping them to change their behavior [7].

The mentioned approach is called as "demand side management (DSM)" in the literature. DSM technique mainly relies on matching present generation values with demand by controlling the energy consumption of appliances and optimizing their operation at the user side, for instance, by shifting the so-called wet appliances such as dishwashers and washing machines from peak time to off-peak time. The importance of energy usage optimization in a smart house can be inferred from the statistical information which indicates that the electricity consumption in the residential sector represents over 30% of the energy consumption of the world [8] and 24% of total electricity demand of Turkey in 2012 [9]. Therefore, a large number of research efforts have been devoted to the application of DSMs. For instance, the effects of Time-of-Use (TOU) tariffs-based DSM program on demand and load shifting were examined for the Italian case by Torriti comparing the results with flat tariffs and it was observed that TOU tariff causes to higher electricity demand and lower price values [10]. In another study, a DSM strategy depending on the interactions among the users was proposed by Mohsenian-Rad et al. so as to decrease the energy cost and peak-to-average ratio of the demand [11]. Besides, the main advantages and challenges of DSM techniques for the applications of smart grid systems were comprehensively investigated by several studies [12,13]. However, most of these DSM-based approaches have dealt with the problem from the perspective of power system. It is apparent that a great amount of power consumption reduction in a power system, especially in peak times, can be accomplished by making use of the savings available in smart homes. Therefore, various studies have focused on the residential applications. For instance, Gudi et al. proposed a load management DSM program-based simulation tool that utilizes Particle Swarm Optimization (PSO) algorithms to optimize the operation of appliances in a house and distribution of energy obtained from renewable sources [4]. The results indicated that considerable cost savings were obtained for both objectives by providing the consumer a real-time analysis with a Graphical User Interface (GUI)-based platform. Furthermore, Di Giorgio and Pimpinella examined an optimal energy management controller of a smart home in case of DSM and TOU tariff and reasonable results were obtained in terms of economic savings [5]. Again for arranging the runtime of household appliances with the aim of reducing the monetary expenses, a DSM method based on time-varying tariff was put forward by Chen et al. [6]. In this study, the authors especially dealt with the uncertainties in usage of electrical devices and