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Modeling for home electric energy management: A review

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ABSTRACT

In recent decades researchers and companies around the world have developed proposals related to Home Energy Management Systems. This paper presents a review of the most relevant literature published on that subject focused on infrastructure, communication media – protocols, variables managed by the system, software and the role of the end user. For this research, around seventy energy management models were studied, and their main advances and contributions were analyzed. In addition, based on this review and the empties observed on existing home energy management models, a preliminary model is proposed. In the proposal, the main elements of the studied models are grouped and the new model is combined with external variables, which influence the implementation of the management system, to give the end-user its proper role as an active part of the electricity value chain, as a strategy to contribute with home energy efficiency providing new demand patterns.

Contents

1. Introduction

Smart Grids have allowed a changing role of the end user, who goes from being a passive consumer to an active user in the value chain of electric energy. Technological, financial and social changes being developed for providing intelligence to the grid require devices with unified monitoring, measurement and control protocols, which results in making real-time assertive decisions regarding energy demand by the user [1]. To make these strategies work, the user must to participate actively in making decisions on energy consumption and own generation. However, this new approach of the electricity sector requires several elements, such as: hardware deployed for the residential and the distribution system level; communication protocols that allow interaction between all actors in the process, including the end-user; and software that allows the control of different variables, which influence the system, and also the implementation of the management strategy.

Concepts related to Smart Grid systems, such as Microgrids and Advanced Metering Infrastructure (AMI) arise in a complementary

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way to achieve a more efficient electric energy management based on communication protocols to facilitate access to generation, consumption and energy costs information in real-time [2]. Likewise, active demand management proposes aggregators, which are entities that contribute to the electricity market balance, through intelligent monitoring and negotiated rates programs, to meet the needs of consumers [3]. In addition, Home Energy Management Systems (HEMS) allow connecting home appliances to the network for remote management based on the combination of the home network and Internet as saving system in real time. HEMS are used to collect data from home appliances with smart meters and sensors to optimize the energy supply and management through the use of that information [4], and relate it with the market behaviour, which helps to reduce consumption and demand in the electric grid (Smart Grids), leading to a growing interest in Demand Response (DR) systems and Demand Management Systems (DMS) [5].

Several authors have addressed the problem of Home Energy Management from different perspectives and using different solutions, such as multi-objective optimization techniques, stochastic processes, implementation of pilot plants, among others. In this paper, besides the technical aspects, strategies and measures aimed at providing greater flexibility and active participation of users are analyzed. This improves the system efficiency with tools such as active management of electricity demand, which through economic incentives, additional facilities provided by the market and the proper use of electricity, makes possible a change on the demand curve [6]. In this way, the presented exploration allows determining the main components of the HEMS, such as: hardware, communication protocols, software development, relationship with the final user, and also the validation of the models proposed by the authors. This information provides an overview about the implementation of each component and the system as a whole, therefore it is possible to establish gaps in the models studied, which allows proposing new models including aspects not taken into account, or extending the existing models.

This paper reviews the scientific literature on Home Energy Management Systems implemented in the last five decades. In Section 2 the models proposed by different authors for managing Smart Grids and Micrograds are shown. Section 3 identifies the main aspects related to Home Energy Management Systems, domotics, communication protocols and smart monitoring of devices. In Section 4 the main models developed about home management systems since the seventies until 2011 and since 2012 until 2014 are presented. Based on this review, diverse home energy management strategies were identified, and several differences as well as common elements and possible gaps for implementing new models were found. It must be highlighted that important advances in this topic have been achieved over the past decades. In Section 5, the authors present a preliminary proposal for the model of home electric energy management, where the “active user” is the central axis together with external variables, which may affect the system depending on the context where the model is implemented. This approach is one of the contributions of this study. Finally, the conclusions of the developed review about the different home management systems are shown.

2. Energy management systems

2.1. Smart Grids management

Information technology and communications play a key role in saving energy worldwide with control, optimization, costs reduction and carbon footprint functions [7]. Smart Grids are an improvement of the energy supply system infrastructure in generation, transmission, distribution and consumption processes [1]. These use self-control technologies to enhance failure detection for a reliable supply, bidirectional energy flows management and vulnerability reduction [8]. In addition, Smart Grids use interoperability between houses creating an opportunity to optimize energy consumption of the client individually and improve the overall system through demand relief in peak hours [9].

Some of the models proposed by different authors for Smart Grid management are:

- Protection systems that can verify and monitor themselves [10].
- The Kuramoto[1] model. The goal is to keep the system in balance or to maintain phase synchronization (also known as phase locking) [11].
- Complex biological systems [12].
- Random networks have been studied with current density passing very low in some areas, and too strong in others [13].
- Neural Networks [14].
- Markov[2] processes. The way in which wind power becomes a necessary ingredient in studies of electric networks. Storage, wind variability, supply, demand, prices and other factors are modeled as a mathematical game [15].
- Maximum Entropy. This goes back to Shannon's[3] ideas on communication networks. Modern research of wireless networks considers the problem of network congestion, and other algorithms as game theory are proposed to reduce it [16].
- OpenADR[4] Implementations. It is an open source of smart grid communications standard used for implementations of demand response for load shedding and to reduce requests during major consumption periods [8].
- The IEEE P2030[5] group, in early 2011 gave guidance on Smart Grid interfaces. The Common Information Model (CIM) provides common semantics to convert data into information. MultiSpeak®[6] created a specification that supports the distribution functionality of the Smart Grid, with a set of integration definitions for distribution software interfaces [17].

2.2. Microgrids management

Microgrids are electric networks that use distributed energy sources which are mostly renewable, and storage devices, in order to meet the demand within an established coverage [18]. Although they can operate interconnected with the electric system, they have the ability of self-supply and operating in isolation [19]. Some of the main techniques to manage the performance and cost optimization for a Microgrid (MR) of residential use are:

- Genetic Algorithm: It applies to the environmental and economical problem for the Microgrid optimization based on real data. NOx, SO_2 and CO_2 emissions, and startup, operation and maintenance costs are taken into account for the cost function [20].
- CCHP – Combined Cooling, Heating and Power of Microgrids with units of distributed cogeneration and renewable energy, is a solution to problems of demand increment, rising costs, supply security and the environment [21].
- MADS – Mesh Adaptive Direct Search method: generalization of pattern search algorithm. The proposed analysis guarantees

[1] Mathematical model used to describe synchronization.
[2] Phenomenon created by Andréi Márkov.
[3] Claude Elwood Shannon, American electronic engineer and mathematician, the father of information theory.
[4] Open Automated Demand Response Communication Standards.
[5] Development project called “Draft Guide for Smart Grid Interoperability of Energy Technology and Information Technology Operation with the Electric Power System (EPS), and End-Use Applications and Loads”.
[6] Specification or standards definition.