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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 Microgrids 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.

the optimization conditions. The algorithm is characterized by searching on the space of test points at each iteration [22].
- Efficient Stochastic Framework: It develops the effect of uncertainty in the optimal operation management of Microgrids. It considers the uncertainty error of load forecasting and the market price with the probability distribution function [23].
- Mixed Integer Linear Programming (MILP) approach: To minimize the costs of a day of energy consumption, DER (Distributed Energy Resources) operation and housework that use electricity are scheduled based on electricity prices in real time and expected renewable energy production [24,25].

3. Home management

The technology for home energy management in the most efficient way with the network is known as Home Energy Management System (HEMS), which allows connecting home appliances to the network for remote management based on the combination of the source network and Internet as saving system in real time. However, previous studies only control home devices and show the energy consumed in a period [26]. Concepts such as Smart Grids or Advanced Metering Infrastructure (AMI) arise for electric energy management and measurement purposes. However, standards and programming interfaces have not been unified for widespread use [27].

Internationally, the harmonization of test protocols and standards for energy efficiency at home is important, since there are barriers such as: different test protocols, weather, electricity or fuel prices, cultural attitudes, production techniques in regions, characteristics and differences in products usage [28]. The purchase of home appliances has increased worldwide, for this reason one of the objectives is to improve energy efficiency with initiatives such as energy labeling [29,30], quality materials usage in electric facilities according to needs, home appliance maintenance and timely detection of energy losses [31].

3.1. Domotics

Domotics concept refers to the automation and control (on/off, open/close and regulation) of equipment and systems of electric and electronic facilities in a centralized and/or remote way [32] and it is determined by an advanced metering infrastructure of the electric network with a smart meter [33].

Together with domotics there are some types of smart homes. A first category relates to the care of people through the detection and recognition of health conditions. A second category captures and stores different aspects that happen at home with multimedia and photos. A third category is surveillance in order to protect. There is also an emerging trend of houses helping to reduce energy consumption by monitoring and controlling home appliances according to energy demand and supply [34].

Domotics systems act on home appliances and home electric systems and each system has its advantages and disadvantages, however, there is a great offer in the market and one or more systems that adapt to every situation [35]. Recent research works are addressing the development at low cost and easy access of supporting systems to detect home activities, for example, the use of arrays of sensors such as motion detectors or contact switches placed on the electric supply board [36,37].

Architecture of domotic systems refers to the structure of each network. Their classification is based on the place in which the "intelligence" of the system resides. The main architectures are: Centralized, Decentralized, Distributed and Hybrid or Mixed [38]. In the network environment there are standards-based methods for the data and messages exchange, including DLNA (Digital Living Network Alliance), based on Plug and Play [39].

3.2. Protocols for home energy management

Communication protocols are the procedures used by domotic systems for communication between all devices with the ability of "controller". Protocols can be open standard type (free use for all), under license standard type (open to all licensed) or owner type (solely for the manufacturer or manufacturers owners) [40].

In the market there are many automation standards for communication which are used in buildings. Some of these are:

- ZigBee: Technology to facilitate communications in the source domain and the optimal traffic concentration [41]. It is a wireless networking standard with low-rate designed for automation and control, employing IEEE 802.15.4 standard as radio layer [42],
- X-10: Home appliances control through the wiring at home [43],
- BACnet: Protocol for building automation and control networks [44],
- Konnex: Standard for home and building control [45],
- LonWorks: Communication network and implementation in a processor [46],
- Jini: Adaptive scalable networks, able to evolve and be flexible [47].

Fig. 1 shows the main protocols used in the four processes involved in the value chain of the electric sector, such as generation, transmission, distribution and the end consumer. Likewise, the relationship of these protocols with communication networks and their interaction within the OSI[7] communication model is observed [48]. Those directly involved with home are highlighted.

3.3. Smart monitoring for home management

A smart sensor is an electronic subsystem with functions of detection, calibration, self-test, decision making (digital processing), communication, or even any combination of them [51]. Wireless Sensor Networks (WSN) are distributed spatially networks with limited data collection, they control and manage information of smart services such as energy [52]. However, other approaches show their disadvantages due to: unpredictable movements, unsteady design (moving objects), ergonomic problems, high dimensionality (tracking is complicated because the exact location) and unavoidable uncertainty (variance and error) [53].

Home appliances can be integrated to a wireless control network using scalable signaling global management, with wide coverage and robustness [54]. The standard IEEE 802.11 has been established as one of the most popular wireless technologies in this regard [55], they synchronize in a set of services to operate in either of two operation modes: independent BSS[8] infrastructure and IBSS where devices form an ad-hoc collision-free multiple access network [56].

The implementation of simple algorithms to reduce consumption during peak hours can be extended by using more developed software attached to a smart outlet, sensors and methods to label each home appliance [57]. The devices must have information technology and the new generation of smart meters, which not only provide energy consumption readings, but also additional information about their use [58].

Some authors have presented their approaches to monitor the load of home appliances. Powers and Margossian [59] show an

[7] Open System Interconnection
[8] Basic Service Set.

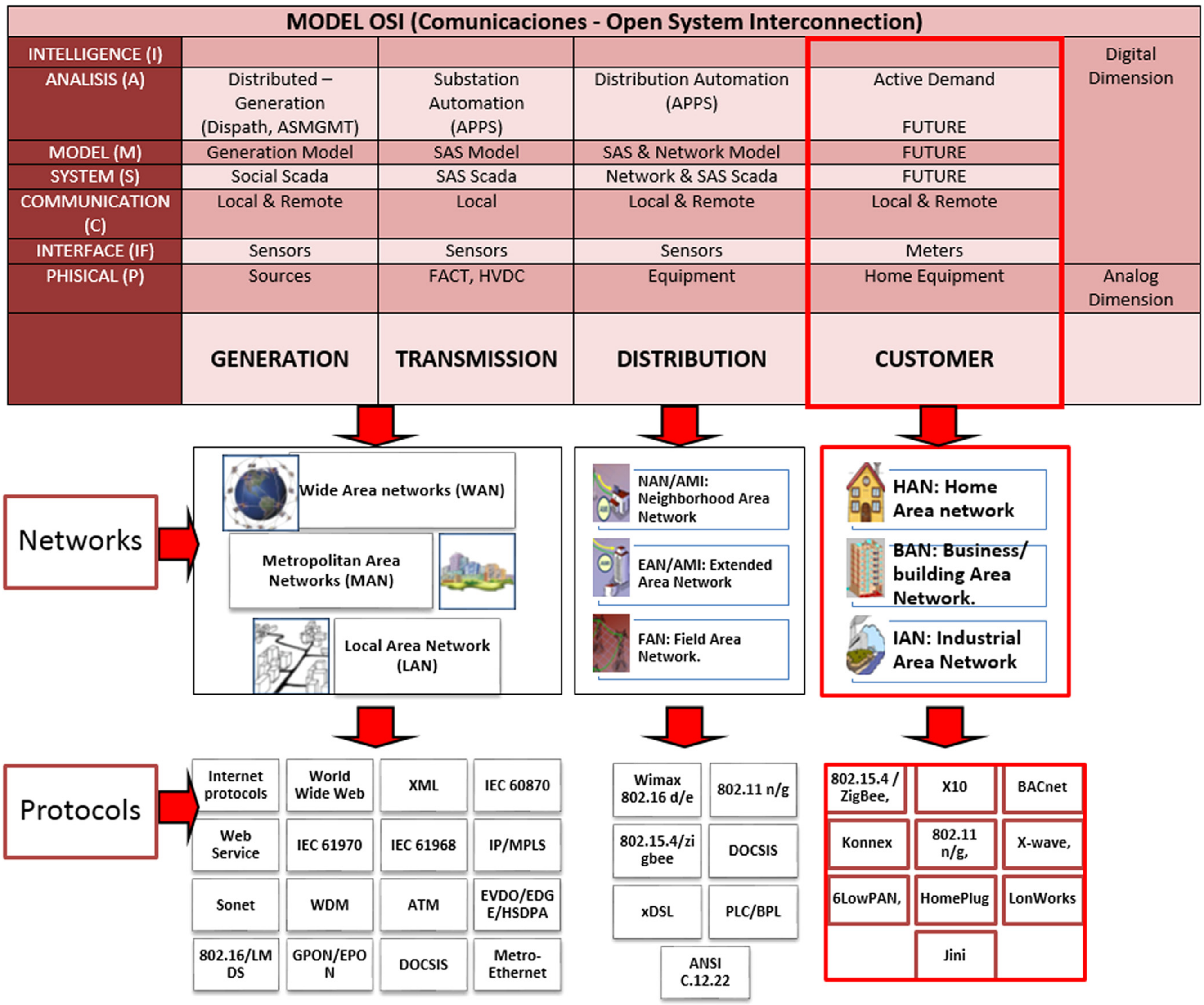

Fig. 1. Protocols used in the electric system attached to the OSI Model [41,48–50].

algorithm with rules based on pattern recognition, which requires at least one sensor by device for adjusting the characteristics of initial operation. Hard [60] establishes a Nonintrusive Appliance Load Monitoring (NALM), which characterizes the power signal in successive stages or events, and they relate to home appliances. Farinaccio and Zmeureanu [61] present an algorithm based on pattern recognition for the total electricity consumption in a house. They assume a constant device, which actually varies with the load and its configuration. Marceau and Zmeureanu [62] show a load disaggregation algorithm that compares each change of operating range of the device with the total energy signal.

On the other hand, Patel, Robertson, Kientz, Reynolds and Abowd [63] show that the abrupt change of electric loads produces electrical noise in transient or continuous way, which allows detecting the electrical noise on the network of certain devices in operation. Younghun, Schmid and Srivastava [64] exhibit indirect sensors to evaluate the energy consumption of home appliances by measuring variations in acoustic and magnetic fields when home appliances are on or off. Ruzzelli, Nicolas, Schoofs, and O'Hare [65] present a low energy consumption, wireless, and low cost solution that integrates device profiles, load storage for later use and automatic learning recognition called RECAP[9].

4. Perspectives of home management system Models

Sections 4.1 and 4.2 describe the evolution of home management systems in recent years, divided in two stages, between 1970 and 2011, and from 2012 to date.

4.1. Home management models proposed between 1970 and 2011

In the seventies integrated infrared sensors were employed, which joined a circuit and their control was done from a microcomputer. These systems did not present economic merits, since implementation costs were very high due to their inflexible technology, which required new infrastructure for implementation and they did not reflect the energy savings [66]. In

[9] Recognition of Electrical Appliances and Profiling in real-time.

Table 1
Summary of home electric energy management models reported in literature (1970–2011).

Year	Model	References
1970	Integrated infrared sensors	[64]
1982	Algorithm for energy management to reduce the cost of electricity	[65]
1986	Combination of semiconductors, microcomputers, and solid state sensors	[66]
1986	Identification of four levels for energy management	[67]
1988	Ubiquitous computing	[68]
1995	Houses to promote the independence of elderly and disabled people	[69]
1999	Aware Home – home with ultrasonic sensors and radio frequency and video technology	[70]
2002	MavHome – house with sensors which acts on the environment through of automating activities	[71]
2003	Grenoble experimental smart home – smart home with a model based on an informatics infrastructure framework, which has three layers	[72]
2005	ECOIS – the awareness of residents to the conservation and reduction of energy demand with saving activities	[73]
2005	PROFESY – combines and optimizes the maximum demand monitors of the network	[74]
2006	Ubiquitous Home – Devices and sensors using a data network of remote connectivity that detects the movement of people	[75]
2006	Optimal algorithm based on game theory for location and activity tracking of a single inhabitant	[76]
2010	Apple – device that shows the status of the electric network of the house with connected devices	[77]
2010	SHEMS – helps to make decisions about demand and efficiency	[78]
2010	Control electricity and heat demand such as the generation and storage of energy	[79]
2011	The energy consumption and the voltage are measured and power is calculated.	[80]

1982, the College of Engineering of the University of Florida developed an optimization algorithm for energy management to reduce the cost of electricity watching the price structure and the time usage or demand, simulating with a computer the electric energy needs of a typical residence for testing the effectiveness of the algorithms [67].

In 1986, the union of semiconductors, microcomputers, VLSI[10] and solid state sensors (mechanical, radiation, temperature and magnetic) for home appliances were implemented in Japan in order to verify their whole work in the management system [68]. Similarly, in [69] the needs of energy management of a facility are analyzed with factors as: operation size, equipment type and geographic location, identifying four levels of energy management: Level 1 – Basic Energy Management, Level 2 – Advanced Energy Management, Level 3 – Total Energy Management, and Level 4 – Total number of applications.

In 1988, the concept of ubiquitous computing was proposed. This employs wired and wireless internet, sensor networks, network devices, control and computer engineering. Humans naturally interact with devices in their environment and perform tasks in a transparent way with regard to computers. The system identifies, recognizes the state of users, interfere with their needs and acts proactively [70]. In 1995, wellbeing houses to promote the independence of elderly and disabled people and improve their quality of life were built in Japan. Sensors were installed in rooms and bathrooms with fully automated devices for monitoring physiological parameters. They were attached to a computer for automatic collection and transfer of data to a main server [71].

In 1999, the Aware Home was implemented, a home with ultrasonic sensors and radio frequency and video technology, all attached to computing environments, which allow tracking people with signal processing, locating lost objects, among others [72]. In 2002, the “MavHome” system was developed, which perceives the state of the house with sensors and in a smart way acts on the environment through drivers by automating activities such as raising the temperature of the house, turning on alarms, kitchen devices, lights, etc. It uses algorithms based on information and forecasting theory, and tracking activity patterns [73].

Grenoble experimental Smart home, implemented in 2003, proposes a smart home with a model based on an informatics infrastructure framework, which has three layers: the application layer that provides monitoring services, the hardware layer having electric devices and an intermediate layer that allows linking the other two. Similarly, this study presents the psychological and cognitive behaviour of people who will use it [74]. Another approach to this problem is proposed in 2005, when an Energy Consumption Information System (ECOIS) was developed. This study focused on the awareness of residents to the conservation and reduction of energy demand with saving activities. The project was focused on the monitoring of energy usage and temperature every 30 min in houses in Kyoto, Japan [75].

PROFESY (PRediction of Optimized load proFiles for Energy management SYstems), developed in 2005, combines and optimizes the Maximum Demand Monitors MDM of the network. It switches off loads when there is a peak and predicts the behaviour of individual nodes. The algorithms use artificial intelligence with neural networks, and rely on a database which contains historical energy management records and environmental data. They opt for a combination of alternatives and choose the most feasible and optimal [76]. In 2006, T. Yamazaki built a real-life test bed called the “Ubiquitous Home”, focusing on services that a Japanese-style house can provide, context-sensitive with the link of devices and sensors using a data network of remote connectivity that detects the movement of people and the position of furniture. The authors installed multiple cameras and microphones in every room, so there is not much privacy. Robots for home service were introduced [77].

In [78] it is presented a management scheme that integrates an optimal algorithm based on game theory for location and activity tracking of a single inhabitant and the correlation between contexts of multiple inhabitants within the same environment (a “Nash H-learning” based approach). Experimental results demonstrate that the proposed framework is capable of adaptively controlling a smart environment, thus reducing energy consumption and enhancing the comfort of the inhabitants. In 2010, Apple presented a patent about using the electric network of houses as data network and for management at energy level. They have a device that shows the status of the electric network of the house with connected devices, observing the consumption being made. It uses Home Plug Power Line Networking that turns every power outlet into a conduit for audio, video and data attached to high-speed wireless technologies. The patent considers communication protocols such as: PLC, X10, HomePlug 1.0, Universal Power line Association and IEEE 643-2004 [79].

In [80] it is developed a new routing protocol called “DMPR (Disjoint Multi Path base Routing)”, based on the IEEE 802.15.4 standard and ZigBee, using Kruskal's algorithm of graph theory. The authors use data mining to build contextual databases and detect data exchange. The system helps to make decisions about demand and efficiency and it is called “Smart Home Energy

[10] Very Large Scale Integration.

Management System (SHEMS)". Also in 2010, an optimization methodology to control electricity and heat demand such as the generation and storage of energy at domestic level was proposed. Various scenarios are simulated and the methodology focuses on the development of control algorithms by analyzing the current situation, objectives, possible scope and observation of real-world systems. The model has a house with micro-generators, heat, electricity, home appliances and a local controller. It also allows the electricity and information interchange between multiple houses [81].

In 2011, it was presented a system located in a room, which can be controlled remotely with a radio frequency ZigBee module and it works under a Wireless Personal Area Network (WPAN) based on the IEEE 802.15.4 standard. The power outlet and the light are controlled and there is a waiting time to cut off energy. With this system, the energy consumption and the voltage are measured and power is calculated, which allows the reduction of energy and provides an easy way to add, delete and move the home appliances to different outlets keeping the information of the domestic device [82]. Table 1 shows the main home electric energy management models between 1970 and 2011.

4.2. Home management models proposed between 2012 and 2014

Since 2012 an increment in the works about home management electric systems has presented, for this reason the most important advances in this field for the last three years are shown year by year.

In 2012, a system that makes full automation of computational and physical systems in a local area including control and management was developed. This system was built in Plug-and-Play universal network architecture and it is accessed through the Internet over the IEEE 802.11 protocol. It uses software written in XML format with information on each device including its URL. An APM environment (Apache + PHP + MySQL) to develop a web server was built in order to provide an external interface for customers. The system manages energy prices and usage [83]. Moreover, iCHEMS is a management system based on the prediction of renewable energy capacity, it uses the Zigbee technology with the IEEE 802.15.4 standard, it has an iCMS (intelligent Cloud Management Server), iPMD (intelligent Power Monitoring Device) and iEMD (intelligent Environmental Monitoring Device). The system manages costs and implementation of a green smart home [84].

In [85] a project with 22 households equipped with heating systems, and home appliances as dishwashers and washing machines is presented. The objective was to observe the electricity supply and demand in the network, based on market mechanisms, as well as time usage of home appliances. Some houses had photovoltaic energy and others wind energy. The software is based on an agent of algorithms called 'PowerMatcher' that aims to enable the economically optimum operation of the device within the conditions established by the end user. This project is called Power Matching City. While Choi, Lee and Lee [86], proposed a management system for apartments with energy-saving facilities, home servers, a centralized server, home appliances and environmental sensors communicated with IEEE 802.15.4 for low power energy metering measuring temperature, humidity, lighting and occupancy. Each main server handles data usage, on–off control and demand-response signaling. The centralized server has information on weather, energy costs and energy usage, and from these it controls energy facilities and home appliances. The proposed system provides optimal energy saving solutions to the apartment complex, including forecast interfaces of monitoring, statistics and control menus.

In 2012 it was also developed an intelligent algorithm for the management of high energy consumption in home appliances with simulated Demand Response (DR), which manages domestic loads according to their priority and ensures energy consumption below certain levels. The authors developed a simulation tool to analyse the potential of DR for residential customers, therefore their load priority and comfort preferences must be established [87].

In 2013 the "Global Model Based Anticipative – Building Energy Management System (GMBA-BEMS)" was presented. From this, the demand changes with the people behaviour to minimize the cost of daily energy without affecting the comfort of the occupants. To validate the model, an application for managing devices such as heating, washing machine and dishwasher was developed [88]. On the other hand, in [89] a Markov decision process-based approach is presented. With the pricing information in real time a customer can change its energy demand to reduce the cost of consumption. The process introduces two power management units (Central Energy Management Unit and Home Energy Management Unit) to study the interaction between them. Mean while in [90] it is developed a HEMS software framework that requires no additional hardware and estimates the amount of electricity consumed from operating system Kernel or T-Kernel and device control information.

In [91], a modular system based on microcontrollers to monitor and control the electricity demand of air conditioners is presented. The system includes the following aspects: energy consumption, control of modules through Internet, available demand control, proposed demand control and electric energy savings. This study was conducted in a university building with 28 classrooms and 56 split. Pisica et al. [92] propose a Home Energy Management System based on microcontrollers to facilitate the use of dynamic operation tariffs in a time frame taking into account user preferences. The microcontroller transmits and receives commands from devices wirelessly. The system has three components: core processor, machine model and a web server.

In [93], it is presented the Autonomous Balancing of Load Energy (ABLE), which provides feedback on energy consumption to encourage householders to adopt more efficient practices about energy usage during specific periods observing the behaviour of the occupants. It uses the information on energy tariffs, recommends where residents can save money and which home appliances should be used during lower activity periods. It employs a unit of data collection with ZigBee as sensor, a Computer Unit (database, automatic learning unit, web) and a Learning Unit that defines the control schemes for devices. Meanwhile the Wireless Communication Technology (WCT) [94] allows the measurement of electric parameters such as voltage, power, and current on home appliances through an interface with detection modules integrated to a XBee module to transmit wirelessly to a centralized ZigBee and data are stored in a database and they are remotely controlled. Home appliances are controlled automatically or manually.

The Energy Management Algorithm with Renewable Energy Sources provides benefits such as savings in the electricity bill, reduction in peak demand and meeting the demand side requirements. The developed mechanism uses the battery state of charge level, the power grid availability and the rates to control and manage smart home appliances and outlets through ZigBee protocol [95]. While in the Routing System for congestion control described in [96] it is used ZigBee to help achieve a faster and cheaper deployment, however there are performance issues. 10 TelosB nodes for a house with an area of 60 m^2 were used and three routing protocols were separately compared: CTP, CTP-ECODA and CTP using a routing algorithm with enhanced features, which optimizes network performance.

In 2013, a consumer-oriented system was developed, associated with cost efficient connection via Internet with Gateways integrating H\lMcast architecture for multicast. The Gateway receives and propagates the information about consumers. Unfortunately, the IP multicast is not commonly available via the Internet due to implementation complexity. It is proposed the consumer integration with Smart Grids enabling households with Gateway to implement applications such as AMI, DSM and VPP (Virtual Power Plants) [97]. The Master Energy Controller – MEC proposed in [98], is a response system to residential demand and pricing setting by time usage as incentives to customers at times of peak demand, peak load forecast, patterns usage of the customer, energy budget, social and environmental factors, and available energy. The devices are interconnected through a self-organization wireless network based on the IEEE 802.15.4 standard. The network communicates with the MEC via Bluetooth as link port. Each network node is implemented using TinyOS software architecture that provides interaction between modules through interfaces interconnected by structured cabling together with low cost Crossbow TelosB hardware.

In [99], the Adaptable Smart Home Energy System is presented. This is a system that considers the relationship between energy usage and the power capacity of the network. It uses factors such as electricity prices, electricity contracts and electricity consumption. The system bases on the dynamic variables (prices, reduction of the required power level, weather conditions, device status, time of day), constraints (electricity contract, plans of electricity usage, spending budget, and welfare) and historical data (heuristic of energy consumption). The system has communication based on interfaces between home devices and connections to external systems. On the other hand, the Agent-Based Home Energy Management System [100], integrates smart metering technologies, preferred users configuration and flexibility, use of external signals as the price for residential energy optimization, network loads and changes in the energy market. Energy management in real time is achieved through the interaction of smart meters with the network (via prices or market incentives), and with Home Energy Management Systems.

Service-Oriented Architecture (SOA) is an approach to build distributed systems. In this system, a linear programming problem and a heuristic algorithm were formulated for optimizing three criteria: user comfort, economical and environmental. The smart home should include: an internal network, intelligent control and home automation. The central computer is able to communicate wirelessly all elements directly to the central node. The user can communicate with the central computer to control the security system, on or off of home appliances, lighting, heating and air conditioning [101]. In [102] expert linear and nonlinear learning algorithms are proposed to predict if a device will be used at some time or not, although it is limited to the following 24 h. This prediction methodology was done using the iRise database containing energy consumption records of 100 homes for a period of one year.

In 2013 an Energy Management System based on the Rete algorithm is also presented. The proposed system has intelligent connectors and sensors that connect to a LAN to communicate. Home appliances are plugged into the smart connectors. Home appliances and sensors information processes IF–THEN rules based on the rete algorithm [103]. Yu et al. [104] developed a dynamic optimization model for stochastic thermal conditions in loads of different features, and a predictive model. The optimization is subject to the power, cost and thermal dynamics, and operates on multiple time scales: detection, control and parameter estimation. On and off control units were implemented. Three types of controllable loads: Dynamic load (HVAC), interruptible load (Plug-in Hybrid Electric Vehicle), and non-interruptible load (as washer and dryer) are considered. The possibility of integrating renewable resources such as solar panels is also considered. The system has a control center that receives information through interruption or control signals with sensors. Consumers take control decisions in real-time about energy usage.

In 2014 the results of a social experiment in a district of Japan were presented. The system was installed in four households in an extremely cold district in Japan for 378 days; data on electricity consumption were collected and stored using smart power points. The authors developed a framework for combining the power network and the TIC as a smart network. They used the IEEE 1888 communication protocol, which has the versatility to be located in a

Table 2
Summary of home electric energy management models reported in literature (2012–2014).

Year	Model	References
2012	Automation of computational and physical systems in a local area	[81]
2012	iCHEMS, Manages costs and implementation of a green smart home	[82]
2012	Power Matching City – the electricity supply and demand in the network, based on market mechanisms	[83]
2012	Measuring temperature, humidity, lighting and occupancy	[84]
2012	Intelligent algorithm for the management of high energy consumption in home appliances with simulated Demand Response	[85]
2013	GMBA-BEMS – the demand changes with the people behaviour to minimize the cost of daily energy	[86]
2013	With the pricing information in real time a customer can change its energy demand to reduce the cost of consumption	[87]
2013	Estimates the amount of electricity consumed	[88]
2013	Based on microcontrollers to monitor and control the electricity demand of air conditioners	[89]
2013	Facilitate the use of dynamic operation tariffs in a time frame taking into account user preferences	[90]
2013	ABLE – provides feedback on energy consumption	[91]
2013	WCT – measurement of electric parameters such as voltage, power, and current on home appliances	[92]
2013	The energy management algorithm with renewable energy sources – uses the battery state of charge level	[93]
2013	The Routing System for congestion control.	[94]
2013	A consumer-oriented system was developed, associated with cost efficient	[95]
2013	MEC – response system to residential demand	[96]
2013	Adaptable Smart Home Energy System – relationship between energy usage and the power capacity of the network	[97]
2013	Energy management in real time is achieved through the interaction of smart meters with the network	[98]
2013	SOA – The smart home should include: an internal network, intelligent control and home automation	[99]
2013	Predict if a device will be used at some time or not	[100]
2013	Intelligent connectors and sensors that connect to a LAN to communicate	[101]
2013	Optimization model for stochastic thermal conditions in loads of different features	[102]
2014	Provides electricity consumption information in real time through the web	[103]
2014	iEMS – The aim is to look at scenarios in different conditions to find the best energy efficiency and responsible demand by users	[104]
2014	Distributed system as demand response to minimize costs	[105]
2014	Includes both consumption and generation by means renewable energy	[106]
2014	Computational experiment including a simulator of home energy consumption, response mechanisms through optimization	[107]

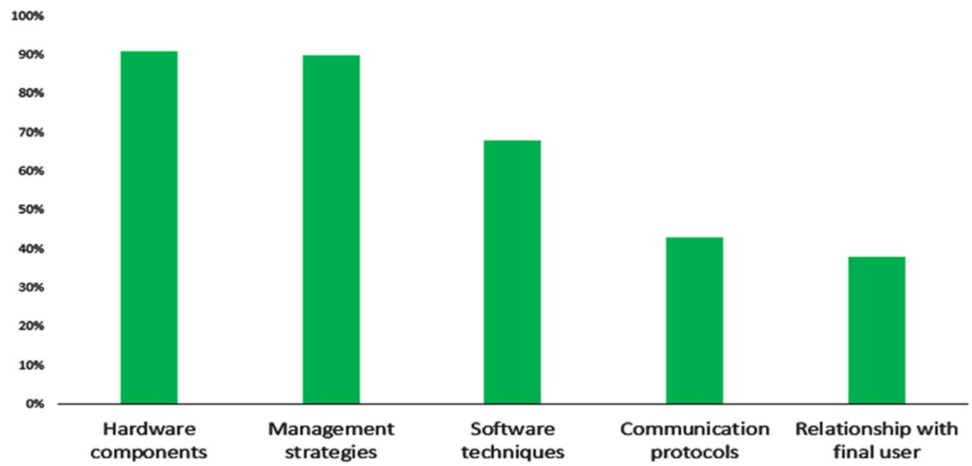

Fig. 2. Percentage of models involving the analyzed characteristics.

HEMS (Home Energy Management System) and a BEMS (Building Energy Management System). The system provides electricity consumption information in real time through the web, and the lists of actions to save energy [105]. On the other hand, the intelligent Energy Management System (iEMS) developed in [106] consists of two parts: a fuzzy subsystem and intelligent lookup table, which is based on rules and fuzzy inputs to produce an output to the intelligent lookup table that feeds of inputs as external sensors, external variables (price, battery storage, environmental conditions), and the behaviour and preferences of users. The second part corresponds to a new associative neural network model able to assign inputs to desired outputs. The aim is to look at scenarios in different conditions to find the best energy efficiency and responsible demand by users, coinciding with their preferences and behaviors.

In [107], it is proposed a distributed system as demand response to minimize costs, in which each user finds the optimal time for operation of home appliances according to prices and schedules. The electricity price depends on the aggregate load of other users, rather than individual load profiles, which lead to lower cost for users and utilities, lower peak demand and lower fluctuation. The system has an AMI for each user that measures electricity energy consumption and communicates pricing information, a PLC that sends signals from each home appliance depending on the response of the demand algorithm and an energy management controller that facilitates communication between devices. In [108] a new Management system that includes both consumption and generation by means renewable energy is presented. ZigBee is employed to measure energy of home appliances and lighting, and a communication modem using Power Line Carrier PLC is used to monitor the solar panels and the communication units of energy measurement. The system monitors the state of solar panels about the capability of detecting voltage, current, and temperature with the IEEE 1901 standard.

Finally, Li et al. present a computational experiment including a simulator of home energy consumption, response mechanisms through optimization, a heuristic method and a computing platform. The authors used regression techniques and optimization algorithms, and the simulation software Equest as virtual test bench to observe the demand response and its evaluation, with variables such as dynamic pricing, seasons and time usage [109]. Table 2 shows the main home electric energy management models between 2012 and 2014.

5. Discussion

In scientific literature, most of the authors have included in their electric energy management systems aspects related to hardware component, communication protocols, software development, relationship with the end user and models validation. Fig. 2 shows the percentage of models that include any of these aspects. 91% involve hardware components, 90% cover validation of the model through energy management strategies, 68% embrace software techniques, 43% incorporate communication protocols and finally 38% take into account the relationship with the final user, a figure considerably small given the importance of the final user in the new global energy scenario.

Thus, there is a need to incorporate to the model the monitoring, control and supervision of home appliances, as well as communication protocols to ensure the reliability of real time information through computing tools developed with advanced algorithms. In addition, the proposed system needs to involve Renewable Energy Sources (RES) in houses, which are part of the electrical system self-generating for self-consumption or for providing energy to the interconnected system, according to individual requirements per housing unit in a bidirectional way. The model allows a better decision-making by the final user taking into account home consumptions, and it offers three operating options: automatic, semi-automatic and manual. The possibility of making home energy decisions allows the user contributing directly to energy efficiency of the system, which transforms that final user in an “active user”.

The importance of applying advances in information technology and communication, power electronics, energy storage devices and generation systems using RES, to contribute with the energy efficiency of the electricity system by involving residential users as active component of the electricity value chain has been established through this research. Furthermore, the improvement in the efficient use of energy may lead to a demand decrease in peak hours and the surplus energy can be fed back to the electrical system. Moreover, this review opens a space to enable users to be actively involved in the processes of energy generation based on RES for self-consumption or for providing energy to the distribution network, creating a new business model.

As a result of the state of art review, a conceptual preliminary proposal of Home Energy Management Model was designed taking into account different aspects related to HEMS. The applicability of the proposed model will be physically over a test system to evaluate its performance, as opposed to the simulations used by many of the models studied in this paper. Another contribution of the proposed model, not found in previous studies, is the insertion of external variables. Even though the active user do not have direct control over the variables, they play a main role when implementing the system because these variables change, between others, according to the place and the social, cultural and economical condition of users.

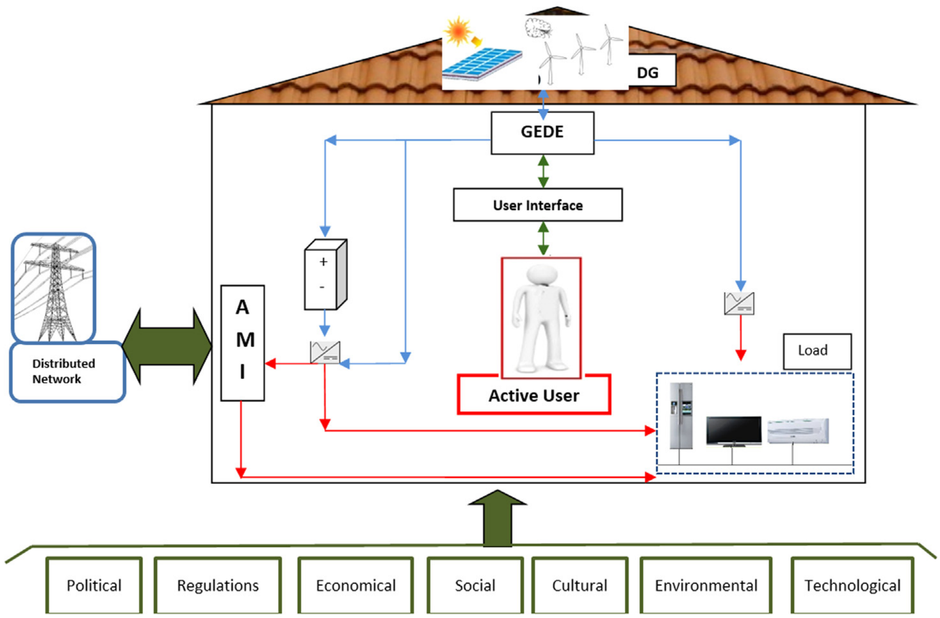

Fig. 3. Home electric energy management model.

In Fig. 3 a preliminary proposal of home electric energy management model is presented, which has three basic elements: infrastructure, communication media and data control, monitoring and supervision. This system operates in three ways: automatic, semi-automatic or as required by the active user, who turns on the central axis of the model making decisions on energy consumption, and contributing in this way to the energetic efficiency at home. The system aims to develop new consumption patterns from which the user will take advantage for his benefit without decreasing comfort levels. The energy supply for the system is projected as follows: the consumed energy at home can get from the distributed network or through installed distributed generation (solar panels and wind turbines); this type of generation can store energy or consume it directly. House loads are in this system, i.e. any device that requires energy to operate, which can be managed by the active user according to its requirements or benefits as economic incentives, environmental issues, etc.

The preliminary model involves scalable smart hardware that allows monitoring through sensors the electric variables that come in or out of connected devices, which can be obtained in real time. Another aspect is the use of adjusted protocols to the reference model OSI, such as the HTTP (Hypertext Transfer Protocol) as an application level protocol, TCP/UDP (Transmission Control Protocol /User Datagram Protocol) for the transport level, IP (Internet Protocol) for network level and variants of the Ethernet protocol at the data link level.

For the physical level, it is proposed to use some types of modulation supported by the Power Line Communication protocol PLC in order to eliminate as much as possible the use of wires. With regard to the software, the design and development of a system based on Web application to work with devices including mobile devices is expected, so it allows performing monitoring, supervision and control of the connected devices to domestic electric installation and distributed generation sources. The proposed system allows the acquisition and storage of basic data such as voltage, current, phase and frequency to determine power and energy and be able to establish the efficiency of a system based on the use of renewable energy.

The model has two types of computer servers, the first called “Management Server”, which manages and stores in a database electrical variables to monitor, supervise and control in a central or remote way, and the second is the “Local Server” to handle the bidirectional signal of load flows and power sources.

A differentiating factor included in the proposed preliminary model corresponds to external variables such as: political, regulation, economical, social, cultural, environmental and technological. These variables were incorporated, since it was observed that they were not taken into account in the reference models reviewed during the research process. They mainly focus on technical aspects of hardware, software and communication. Also, the influence of these variables on the model affects its behaviour according to the external environment where it is applied. The influence of each of the variables in the model is briefly explained as follows:

- Political: state trends to practice and implement residential energy management models with the intention of improving any weaknesses in this sector for the society.
- Regulations: laws and norms which directly or indirectly affect in this type of residential management initiatives.
- Economical: financial interests that may affect companies involved in the value chain of the energy sector with the implementation of this model at home.
- Social: adaptation of users to employ these systems at home regardless of age, gender, social class, etc.
- Cultural: training to learn to interact with this type of initiatives to use the capacity of efficient and assertive energy use by active users who handle these systems.
- Environmental: reduction of environmental pollution using distributed generation at home.
- Technological: fast variability of technological elements designed and developed for this type of systems.

Those external variables allow a direct relationship between the environment in which the system is implemented and its operation may depend somewhat on them, since, depending on where it is located, this is employed by the “active user” differently.

The model presents differentiating elements from other models analyzed in the state of art revision, since it allows the participation of users in making energy decisions becoming active part of the system as “active users”, which contributes directly to energy efficiency at home; Likewise, the inclusion of external variables that influence the proposed model in different contexts is a new factor.

6. Conclusions

Advances have been made from the technological point of view, under the framework of communication protocols, data networks, control and protection devices and management models, which allow inferring that there are opportunities to propose new models taking advantage of these technological advances to integrate them in the same environment in order to make rational use of energy at home and explore new business opportunities nationally and internationally.

The model proposed by the authors facilitates the role change of a passive user to an active user in the value chain of the electric energy to control, monitor and supervise in real time either remotely or directly any home appliance, which can be achieved through the use of systems that manage energy of devices located at residential level, using monitoring infrastructures, communication protocols and computational algorithms, also considering the impact of political, regulatory, economical, social, cultural, environmental and technological variables.

With the rise of electric Smart Grids, it is required to make load sharing according to system operation, therefore it is necessary to propose a new type of adaptable electric facilities, so that the topology can be changed by using electric, electronic or electromechanical devices in order to make load sharing according to the best system operation.

Regarding social aspects, the implementation of a prototype as the described and the analysis of its operation results will allow having a basis to propose State policies about the recognition and payment of the generated energy at home, recognition that must be made by the network operators of the interconnected system, and in order to motivate strategies to reduce energy demand in peak hours by changing the current regulation.

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