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Development of a Home Energy Management System based on the measurement and control of electricity consumption of home appliances

by

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SUMMARY

Electrical utilities around the world are working toward the implementation of demand response programs, which are focused on either reducing electricity usage or shifting its use at times of high wholesale marketing prices. These programs try to involve the consumer participation in the operations of the electric grid. One of the goals of the Smart Grid concept is to develop grid modernization technologies, tools, and techniques for Demand Response in order to help the electricity providers not only to save money through reductions in peak demand, but also to defer the construction of new power plants and power delivery systems, particularly, those reserved for using during peak times. Energy Management Systems are an essential part of the Demand Response concept, since these systems offer tools to the consumers to avoid unnecessary use or expenditure of energy inside the home.

In this work, a home energy management system that measure and register household electricity consumption and costs is described. The system permits to build a home energy network by connecting wirelessly smart appliances and smart meters by means of In-Home Displays. The system carries out electric measurement consumption, which enables to control the operation of smart appliances such as washing machines, refrigerators and other white goods. The system is based on an electronic module, the In-Home Display, capable to communicate with the smart appliances configured in the network, in order to obtain their consumption and control their operation according to the total household demand. Additionally, this module is capable to communicate with an electronic energy meter that supports bidirectional communication (utility and end-user) for the purpose of obtaining information regarding the total consumption, and receiving commands and notifications from the electricity supplier.

KEYWORDS

Smart Grid, Demand Response, Home Energy Management Systems, Energy Efficiency, Smart Appliances, Smart Meters, In-Home Displays.

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1. INTRODUCTION

Energy consumption can be divided into the major energy consuming sectors as commercial, industrial, residential and transportation. Some reports from EERE (Energy Efficiency and Renewable Energy) indicate that in California State energy consuming are: commercial 19%, industrial 23%, residential 19% and transportation 40%. Other example is the consumption in Texas State: commercial 13%, industrial 49%, residential 14% and transportation 24%.

In the residential sector, electricity is consumed mainly by lighting devices, HVAC (Heat Ventilation and Air Conditioned) and appliances. According to EERE data, the energy consumed by appliances represents approximately 13% of the total energy consumption in the home, with refrigeration, cooking, and laundry at the top of the list as shown in figure 1.

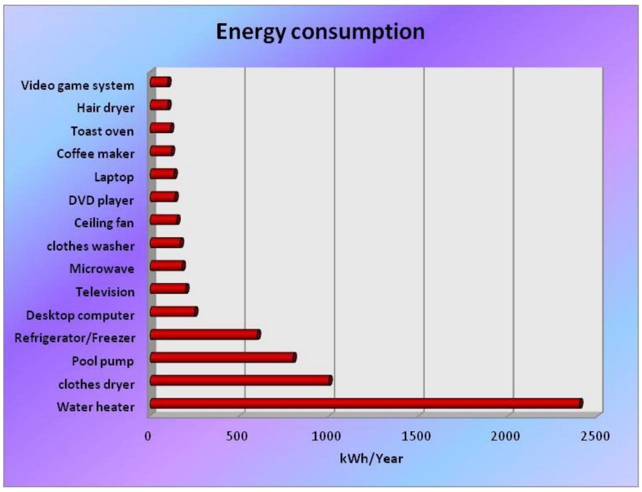

Figure 1 Typical amount of energy consumed annually by household appliances.

Efficient energy use or energy efficiency has become a very topical issue for the international community interested in promoting the implementation of energy saving concepts originated by the urgent need to reduce carbon dioxide emissions in the atmosphere. Energy efficiency refers to the optimization of energy consumption to reduce energy usage without reducing the quality of services with the least possible impact on the environment. In this context, it is important that end-users implement a plan for energy efficiency in their facilities, in order to make a rational and efficient use of energy; hence, it is necessary to count with tools that facilitate the implementation of these actions.

Advanced Metering Infrastructure (AMI) typically refers to the full measurement and collection system that includes meters at the customer site, communication networks between the customer and a service provider, such as an electric, gas or water utility, and data reception and management systems that make the information available to the service provider. Among all the elements, smart meters play a fundamental roll to integrate an AMI system.

At the consumer level, smart meters communicate data consumption to both the end-user and the service provider. Smart meters communicate with In-Home displays (IHD) to make consumers aware of their energy usage. Furthermore, electric pricing information supplied by the service provider enables load control devices like smart thermostats to modulate electric demand, based on pre-established consumer price preferences. Figure 2 shows a typical AMI system that incorporate an In-Home Display, a smart meter and smart appliances (Home Energy Management System).

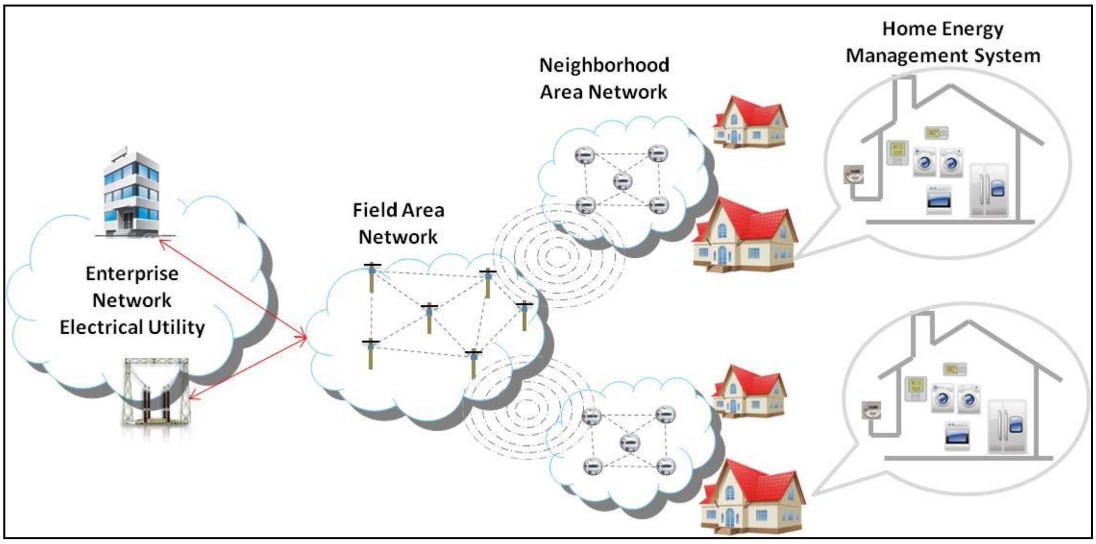

Figure 2 Typical AMI systems interoperating with HEMS.

2. ENERGY MANAGMENT SYSTEMS

Energy Management Systems (EMS) refers to an automated system that is designed specifically for monitoring and optimizing the use of energy in end-user facilities, such as a building or group of buildings, factories or homes. EMS can reduce wasted energy by adjusting heating and cooling usage with a smart system. A typical EMS collects data from energy meters, analyze it and identify opportunities for greater efficiency. Most of these systems also provide facilities for the reading of gas and water meters. EMSs are classified according to their application into three main groups: Home Energy Management Systems (HEMS), Building Energy Management Systems (BEMS) and Factory Energy Management Systems (FEMS).

HEMSs consist in applications that provide information about home electricity consumption and its cost in real time o in defined time intervals. These systems also include functions that enable the consumers to increase the electricity consumption, as well as reduce the energy usage by using local information (neighbourhood) or demographic (particular area of a city).

HEMSs as an important part of the Smart Grid are focused on the power consumer side in which home appliances (e.g., air conditioner, dishwasher, dryer, refrigerator, kitchen stove, and washing machine) with smart meters can be monitored and controlled by especial devices to optimize the energy consumption. These systems may include some specific hardware to control appliances, thermal switches and other devices in the house that are powered with electricity. Functions like energy micro generation management, energy storage and smart charge may also be included. Applications for the electricity supplier include de Demand Response (DR) and energy efficiency programs.

The HEMS usually include a home device to deploy information called In-Home Display or IHD, which is designed to operate as a human machine interface inside the home. The IHD generally presents information related to energy consumption, electricity rates, and operating states alarms of system elements. It integrates functions of data deployment, communication and remote control of electrical loads and lighting devices. It also integrates standardized communication interfaces with the intelligent power meter to exchange information with it or with systems outside of the home through the electricity smart meter.

3. SMART APPLIANCES

Smart appliances are devices provided with advanced functions such as: communication with other devices, remote control and monitoring operation, and automatic start and stop operation, among others. Communication capabilities allow exchanging information with other electronic devices inside the home and with external systems. Inside the homes, smart appliances can be monitored and controlled by means of IHDs, since they have the ability to obtain the operational status of each smart appliance. This information is used to send control commands to start or stop an operation. Outside the homes, the smart appliances can interact with the electrical utilities exchanging information related to its energy use, control of peak demand and management on the demand side.

Trends in the design of smart appliances are oriented to integrate electronic devices that allow continuous monitoring of energy consumption and some parameters of the electric grid, for instance voltage, current and frequency of the line. The monitoring of these parameters makes possible to detect the most common problems in electricity supply. Some HEMSs act over smart appliances according to the levels of certain electrical parameters. For example, low voltage permits inhibiting some of its functions until the power supply is stabilized again. This action helps extend the life of the appliance by not subjecting it to extreme operating conditions, and helps to supervise the operation of the electrical grid, benefiting the user and the supplier of the electric service.

Another trend is focused on the registration of individual consumption of each smart appliance in order to transfer it to the HEMS. The record of electricity consumption can be done in two alternative ways: 1) by applying algorithms that carry out the analysis of power signals or, 2) by calculating the energy consumed based on voltage and current measurements. Present electronics measuring technologies are in favor of the latter method.

4. SYSTEM DESCRIPTION

This work describes a Home Energy Management System developed to allow new appliances to be incorporated into the scheme of “smart appliances”. The HEMS includes the design of three proprietary electronic modules: an electronic module that is integrated into the normal appliances, an In-home-Display that performs the control of the system, and smart power outlet module. The method selected to manage home energy consumption more efficiently is based on measuring and recording the electrical parameters in each of the apparatus in order to determine its contribution to the total home consumption.

The first electronic module was designed to be integrated into normal appliances (washing machines, refrigerators and electric stoves) to test its functions and turn them into “smart appliances”. This module has the capabilities for measuring electric parameters (voltage, current and energy), and communicate with both other devices and the control operation module of the appliance. The second electronic mode is an In-home-Display, which is capable to communicate with the modules integrated into the “smart appliances” in order to obtain information about their energy consumption and status, as well as to send commands to start or stop their operation. Finally, a smart power outlet module, similar in shape to an AC power plugs, was designed. This module possesses remote control operation and has the capacity to measure and register electric consumption of no-smart appliances (TV, micro-oven, etcetera).

The energy management system was tested using tree “smart appliances”, an In-Home Display, one “smart power outlet”, a Human Interface Machine (HMI) running in personal computer and a smart meter. The management system has the ability to communicate with a smart electronic meter to monitor global household consumption, and to transfer information related to “smart appliances” consumption and the levels of electrical grid parameters to the electric utility. To communicate the In-Home Display with the smart appliances, the smart power outlet and smart meter, a Home Area Network (HAN) was implemented using wireless and wired communication. Wireless communication was carried out using ZigBee, and wired communications was achieved via low voltage Power Line Communication (PLC). These types of technologies satisfy the characteristics of the communications networks that ingrate an AMI system.

The In-Home Display is the central element of the Home Energy Management System, its main functions are storage and display of data, communicate with smart appliances, monitor and control of all electronic and electrical devices located inside the home. It has the hardware and software interfaces to communicate with a smart meter, and obtain from it the total household consumption with the intention of showing it to the user when it is required. The In-Home Display can also link with the electric utility control centre through the smart meter and its AMI system as illustrated in figure 3.

The appliances or electrical loads, for example microwave ovens, televisions, computers, among others, which do not have advanced functions, have been called "non-smart appliances". These devices can be incorporated to the HEMS using the smart outlet contact module, which has measurement, control and communication capabilities that allows measuring and recording their consumption. The information coming from the appliances and the smart meter is obtained by the energy management system via the In-Home Display. This information contains the total home electricity consumption pattern and the contribution of each appliance. The data displayed to the users allow knowing the consumption of their electrical charges and what devices consume more energy, which help them to make decisions on the appropriate use of the energy. For example, when the price of electricity or energy demand is lower, end-users can consume electricity (wash clothes or turn on air conditioners).

Hence, residential users of electrical service can manage the energy consumption information provided by the system manually, scheduling the operation and use of appliances at times of lower demand or lower electricity prices. If the utility has its electrical infrastructure operating in the smart grid concept and considers the implementation of programs for Demand Response, the home energy management system described in this work has the ability to receive commands from the utility offices to stop, postpone or schedule the operation of some appliances, thereby helping to control the demand curve. Consequently, home electrical loads can be controlled remotely, decreasing its use during peak hours and incrementing it the rest of the day.

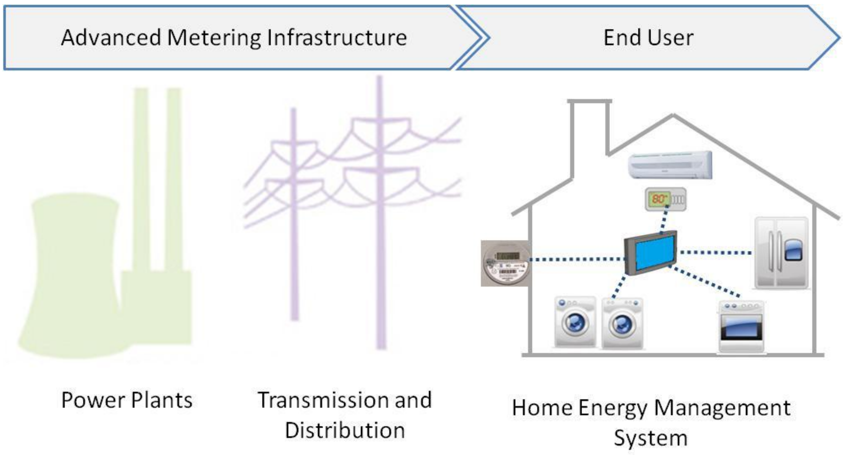

Figure 3: HEM system operating environment.

4.1 HEMS basic operation

As previously mentioned, the Home Energy Management System was tested using the following elements:

- An In-Home Display.
- Three appliances (a washer machine, a refrigerator and an electric stove) equipped with an electronic module to convert them into "smart appliances".
- A smart power outlet for controlling and measuring the no-smart appliances.
- A HMI to monitor the management system for the user.
- A smart meter with two-way communication capability.

A communication network to intercommunicate the elements of the HEM system was implemented using two different media; the former was based on the Zigbee wireless communication, and the latter make use of the electric grid as a means of communication via PLC as shown in figures 4 and 5.

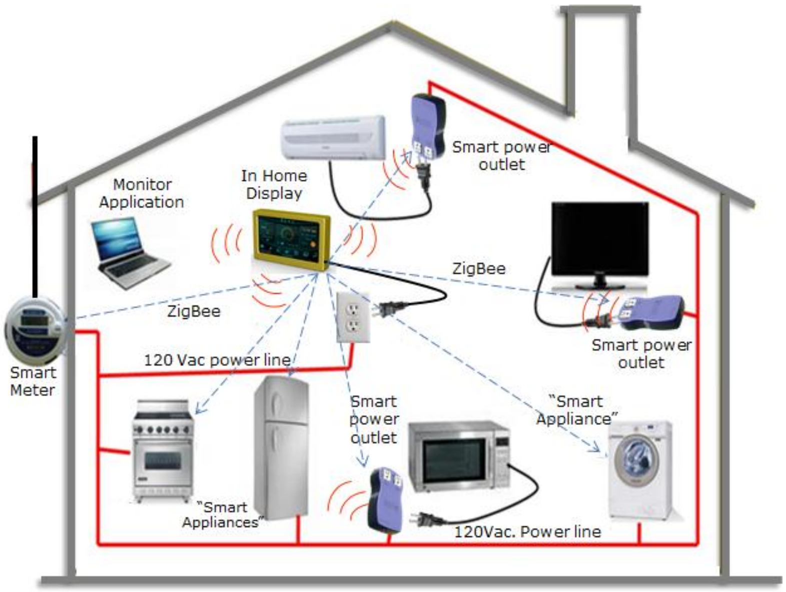

Figure 4: HEMS with ZigBee communications network.

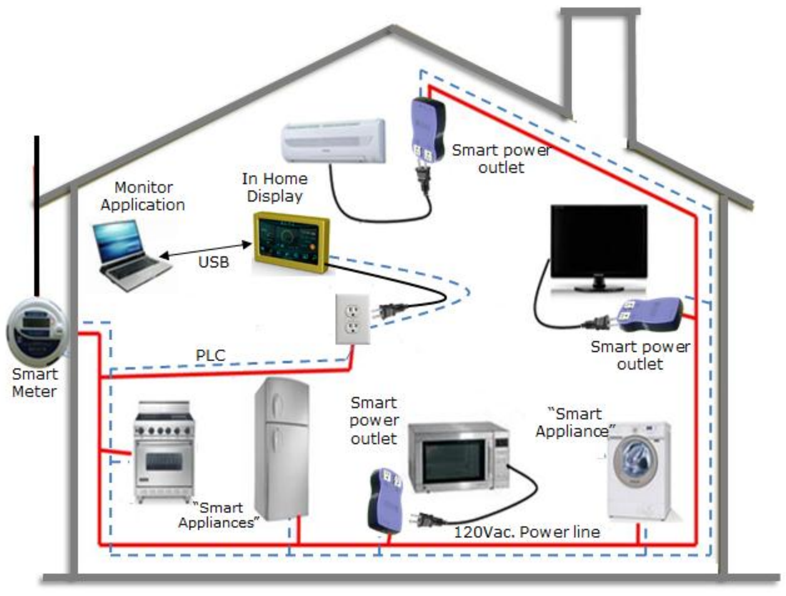

Figure 5: HEMS with PLC communications network.

The system basic operation consists in reading both the energy registered by each appliance and by the smart meter; subsequently, the system compares the total home energy consumption with a reference value of consumption that was programed previously in the In-Home Display. If the total energy is more than the reference value, an alarm is activated to indicate that it has exceeded the programmed level of consumption. Using individual consumption, the In-Home Display determinate what appliance has the major consumption, and shows it on the screen for user's knowledge. Moreover, the In-Home Display reads the voltage registered by the "smart appliances", with the aim of verify if they are working between the minimum and maximum levels allowed. In consequence, the In-Home Display sends a stop or pause command to the appliances that are operating with voltages out of range in order to prevent damage in them. The algorithm that performs these tasks is described in the flow diagram show in figure 6.

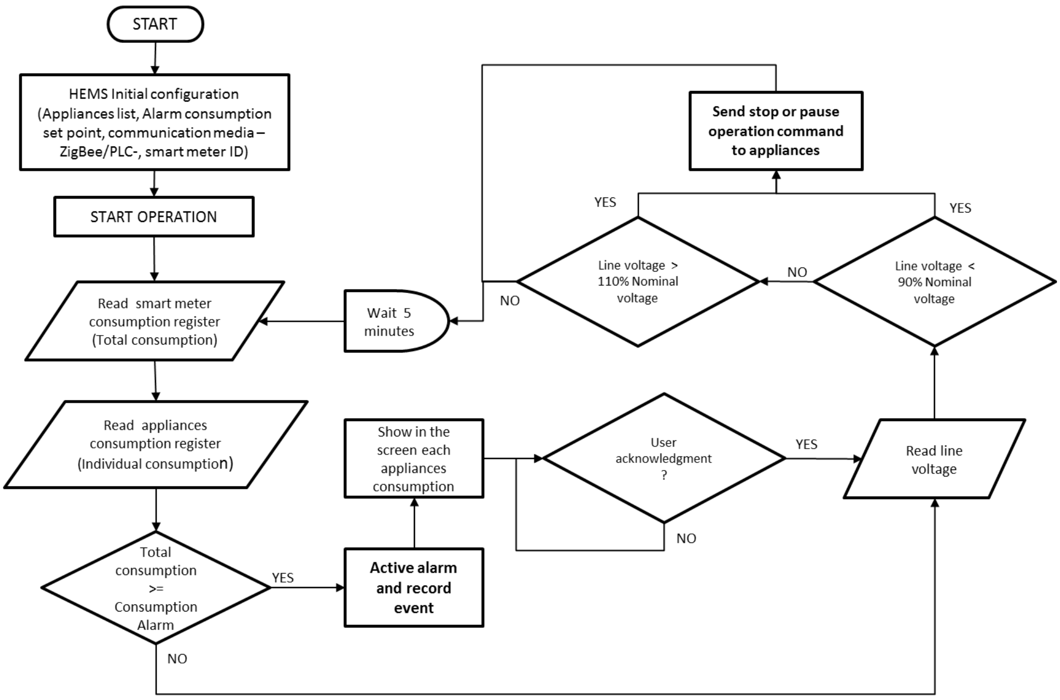

Figure 6: HEMS operation.

5 CONCLUSIONS

A HEM system is a tool for consumers in residential sectors that help them to control their energy consumption. It can also help reducing the energy demand and therefore the amount of resources employed to generate it, thereby reducing emissions of pollutants to the environment created from the power plants. Key elements of the HEMS are the smart appliances. This work presented the design, implementation and tests of a Home Energy Management System consisted of an electronic module that is integrated into the normal appliances to convert them into "smart appliances", an In-home-Display that performs the control of the system, and a smart power outlet module that is used for the inclusion of "no smart appliances". The system was tested successfully incorporating a Human Machine Interface and a smart meter. The HEM system performs the managing of consumer's energy based on the remote measuring of the energy consumed by each appliance, using a communication network implemented via ZigBee and PLC. All the results have been most encouraging and suggest that the system could be applied for energy management in real environments such as buildings and factories.

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