DEVELOPMENT OF A HOME ENERGY MANAGEMENT SYSTEM BASED ON THE MEASUREMENT AND CONTROL OF ELECTRICITY CONSUMPTION OF HOME APPLIANCES

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Abstract: This article describes a home energy management system that estimates household electricity consumption and costs. The system permits to build a home energy management system by connecting wirelessly smart appliances and smart meters. The system carries out electric measurement consumption, which enables to control the operation of s*mart appliances* such as washing machines, refrigerators, electric stoves and other white goods. The system is based on an electronic module capable to communicate with the *smart appliances* integrated in the system, in order to obtain their consumption and control their operation according to the total household energy demand. Additionally, this module is capable to communicate with an electronic energy meter that supports two-ways communication (electrical utility and consumer) for the purpose of obtaining information regarding the total consumption, and receiving commands and notifications from the electricity supplier.

1 INTRODUCTION

Efficient energy management plays an important role to lower the energy consumption, helping to close the gap between supply and demand of electricity; consequently, reducing carbon dioxide emissions.

Under smart grid schemes, communication is an essential process that allows the transfer of information between the utility company and the end users, and to achieve this, electronics devices as smart meters are fundamental parts of the process. Figure 1 illustrates a typical pattern of electricity supply in the context of smart grids, where the power originates at power plants and passes through the transmission and distribution to residential electrical installation of the end user and final consumption in electrical and electronic equipment. Electricity supplier quantifies the users consumption via smart meters, which are devices with advanced metering capabilities (energy received and delivered) and two-way communication that provide information related, mainly, to the generation, transmission, distribution and consumption.

This information is intended to help improve the efficiency, reliability, availability and security of electricity supply and efficient use of electricity.

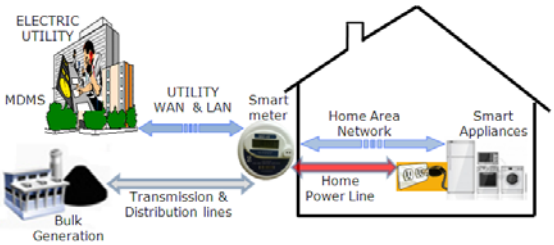

Figure 1: Simplified diagram of the operating environment of smart appliances in the context of smart grids.

Some studies indicate that 70% of global electricity consumption is distributed as follows: industry (31%), data management centers (2%), buildings (18%), transportation (28%) and homes (21%) (EERE, 2006).

In the residential sector, electricity is consumed mainly by lighting devices, HVAC (Heat Ventilation

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and Air Conditioned) and appliances. According to EERE (Energy Efficency and Renewable Energy) data, energy consumed by appliances represent approximately 17% of total energy consumption in the home. Refrigerators, washing machines, clothes dryers and electric stoves top the list of consumption as shown in figure 2 (U.S. Dept. of Energy).

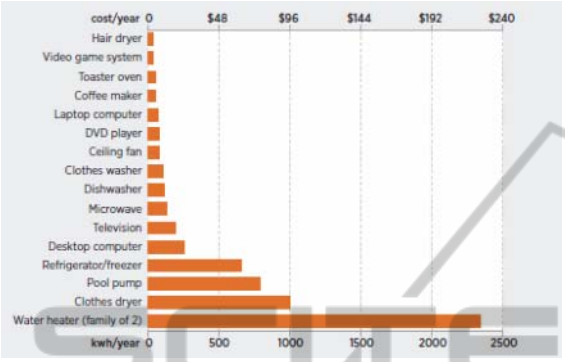

Figure 2: Typical amount of energy consumed annually by household appliances.

Home appliances are electromechanical machines commonly used to perform tasks for the home maintenance; these apparatus are classified by their color, although that is not a rule. Black or gray appliances are usually dedicated to the entertainment (TV, DVD, tape recorder, radio, etc.) and white appliances are linked to cleaning tasks and food treatment related functions. Several global studies show that the appliances contribute with a high percentage of the total home energy consumption.

Appliances are subject to transformations originated by technologic innovations resulting in new devices with more advance functions than traditional appliances. These new devices contribute to life quality improvement, giving solutions that cover some of the domestic needs as comfort increase, safety and energy saving.

Currently, these devices are provided with advanced functions such as: communication with other devices, remote control and monitoring operation, automatic start and stop operation, among others. By the above, appliances with these characteristics are called "smart appliances".

Efficient energy use is 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. Operating costs of the appliance are paid regularly by the user in energy bills throughout its lifetime. In this context, it is important that the end user implements a plan for energy efficiency at home in order to make a rational and efficient use of energy, it implies the generation of an energy saving culture; equally important are the technological capabilities of the appliances that are used at home, to make easier the implementation of these actions by changing present consumption habits.

2 SMART APPLIANCES

Smart appliances incorporate technologies friendly with the environment and the mechanisms to save energy that promote energy efficiency and incorporate communications capabilities that allow the exchange of information with other electronic devices inside the home and with external systems. Communication with the first ones allows giving structure to intelligent control systems inside the home, and communication with the second ones, permits the remote programming of the operating modes of the smart appliances, the monitoring of its states of operation and the measurement of the energy consumption either individual or collective.

Communication with external devices, in particular with the utility company, allows the smart appliance the opportunity to exchange information related to energy use, the control of peak demand, control of emergency on the electrical system, inside and outside the home (voltage variations and power outages), and in general can contribute to the implementation of ways to promote the active management on the demand side.

The trend in the design of smart appliances is oriented to integrate electronic devices that allow continuous monitoring of energy consumption and some parameters of the grid. The voltage, current or frequency of the line, are examples of such monitoring making it possible to detect the most common problems in electricity supply. The system acts accordingly, for example, inhibiting some of its functions until the power supply stabilizes again. This action helps extend the life of the appliance by not subjecting it to extreme operating conditions and helps to oversee the operation of the electrical grid, benefiting the user and the supplier of electric service.

Another trend is directed to the registration of individual consumption of each smart appliance to transfer it to the Energy Management Systems (EMS). The record of electricity consumption can be done in two alternative ways: 1) applying algorithms

for analysis of power signals or, 2) calculating the energy consumed from measurements of voltage and current signals. Current electronics measuring technologies are in favor of the latter method.

3 HOME ENERGY MANAGEMENT SYSTEMS

The EMS refers to a computer system which is designed specifically for the automated control and monitoring of the heating, ventilation and lighting needs of a home, a building or group of buildings such as university campuses, office buildings or factories. Most of these energy management systems also provide facilities for the reading of electricity, gas and water meters.

Energy Management Systems 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).

Home Energy Management Systems consist in applications that provide information about electricity consumption into a home and its cost in real time o in defined time intervals. These systems also include functions that enabled the consumer increase efficiency in electricity consumption, as well as reduce the energy usage by basing on local information (neighborhood) or demographic (particular area of a city).

These systems may include some specific hardware to enable the information exchange and/or the appliances control, 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 alarms of operating states 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.

4 SYSTEM DESCRIPTION

The Home Energy Management system presented in this paper were developed in order to obtain the adequate technology to be incorporated in new appliances, so the development consisted in design the hardware and firmware required; also carry out laboratory test under controlled environment of the system.

Electronics modules with advanced capabilities as electric parameters measurement (voltage, current and energy), communications and appliance operation control were designed and manufactured as part of development. These modules were incorporated inside appliances equipped with electronic controls, in order to convert them in “smart appliances”.

According to an evaluation of actual technologies applied in this theme, the method selected to manage energy consumption within the home in this system, is based on measuring and recording the electrical parameters in each of the apparatus, in order to find how each appliance contributes to total home consumption and thus manage efficiently use of energy.

Likewise, other device was designed and developed to control and link with the modules mentioned above, this device is known as “In-Home Display”. This device has capabilities to communicate with each “smart appliances” in order to obtain information about their energy consumption and status, as well as send commands to start or stop their operation.

By the above, the Home Energy Management system was composed of “smart appliances” as washing machines, refrigerators and electric stoves, as well as devices similar to AC power plugs with capacity to measure and register electric consumption of no-smart appliances (TV, micro-oven, etcetera), an In-Home Display and a smart meter.

The energy management system presented is set according to the scheme shown in Figure 3 and is comprised of the following devices and equipment: smart appliances, an In-Home Display, smart power outlet contact with measurement capability and remote control, and a HMI (Human Interface machine) running in personal computer and a smart meter. The management system has the ability to communicate with smart electronic meter to monitor global household consumption and transfer information related to consumption, energy use and electrical parameters of the electric utility, if this function is available.

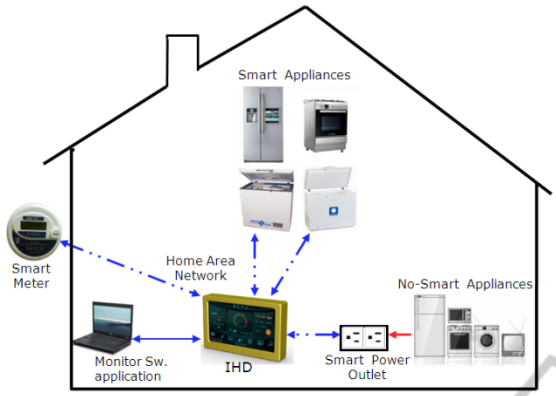

Figure 3: Home Energy Management System Scheme.

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 two technologies wireless (protocol ZigBee) and the power line of the home (PLC in low voltage).

The In-Home Display is one of the central elements of the management system, integrates storage and display of data, communication, monitoring and control of all electronic and electrical devices in the system. It has the hardware and software interfaces to communicate with the smart meter, and get from it the total household consumption to show it to the user when required. It can also link with the control center of the electric utility through the smart meter (F. Casellas, 2010) and its Advanced Metering Infrastructure system (AMI) (Nancy Brockway, 2008) as illustrated in figure 4.

The appliances or electrical loads such as microwave ovens, televisions, computers, among other that have no advanced functions such as communication, measurement or control have been called "non-smart appliances". For these was developed a smart outlet contact with measurement and reporting capabilities, which connect these devices to measure and record their consumption and thus integrate them to the power management system.

With the information obtained from the appliances and the smart meter, the management system via the In-Home Display presents to the user information related to the total electricity consumption pattern of the home and the contribution of each appliance. These data allow the user to know the consumption of their electrical charges and what devices consume the most, in order to make decisions on appropriate use, for example in times of lower demand or lower price of electricity. This in order to foster a culture of energy saving.

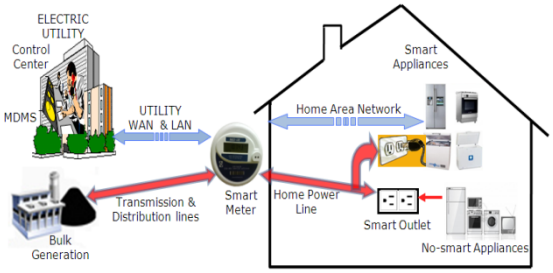

Figure 4: HEM system operating environment.

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 power company has its electrical infrastructure operating in the smart grid concept and considers the implementation of programs for Demand Response, the system of home energy management described has the ability to receive commands from the offices of the utility to stop, postpone or schedule the operation of some appliances and thereby help control the demand curve, diminishing during peak hours and incrementing the rest of the day via the remote control the home electrical loads.

The energy management system includes a software tool that lets you check the consumption information stored in the In-Home Display. This software runs on a laptop that connects to the USB port of the In-Home Display. With this tool the consumer can create your own consumption record for future reference or analysis in order to minimize your energy consumption.

4.1 System Implementation and Laboratory Test

As previously mentioned, the Home Energy Management System consists of the following elements:

- A module In-Home Display.
- Appliances as washer machine, refrigerator and electric stove, each one equipped with an electronic module to convert it in “smart appliances” (M1).
- A smart power outlet (M3) for measure consumption and control of no-smart appliances.
- A HMI to monitor the management system for the user, executable on a computer and interface to the In-Home Display.

- A smart meter with two-way communication capability.

With these elements two systems were implemented in laboratory in order to test the functionality and validate data obtained from each appliance. Also compare the information related to energy consumption provide by the smart meter and the appliances.

A communication network to intercommunicate the elements of the management systems will be held in each one using two different media; first one based on the Zigbee wireless communication protocol and second one using the electric grid as a means of communication with power line communication, PLC as shown in figures 5 and 6.

The laboratory tests consisted in evaluates electric parameters measurement, the communication between each element (ZigBee and PLC), control the appliances operation remotely and carry out an energy balance between the meter and the appliances.

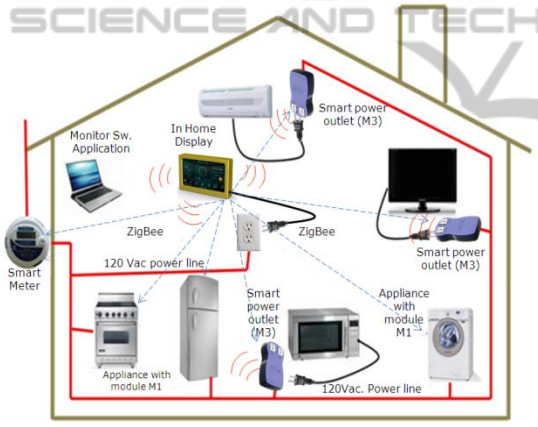

Figure 5: ZigBee communications network.

4.2 Test Results

To validate the measurement and register of voltage, current and energy in the appliances, several data were obtained from the electronic modules installed inside the appliances and were compared with reads obtained from a voltmeter, an ampere meter and a watt-hour meter. The results were the expected due to the accuracy calculated was lower 1%, as was specified.

Control and status commands have been defined previously to control and monitoring the appliances, hence to validate them, some commands were sent to the appliances from the In-Home Display. The results obtained were successful.

With respect the communications, both technologies ZigBee and PLC were tested, thus obtaining correct results.

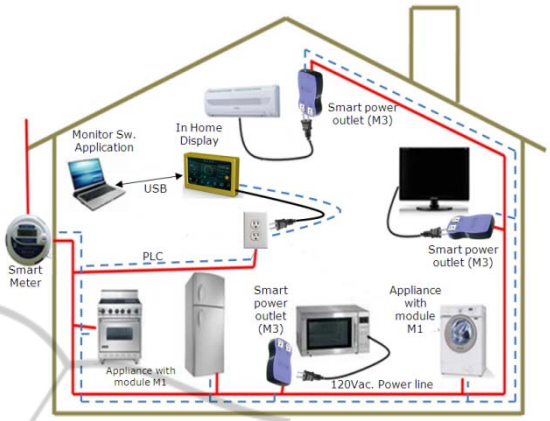

Figure 6: PLC communications network.

Should be noted that to evaluate in a more comprehensive, test field must be applied to the Energy Management System describe in this paper.

5 CONCLUSIONS

A HEMS is a tool for consumers in residential sectors that provide the ability to control their energy consumption. It can also help reducing the energy demand and therefore the amount of resources to generate it, thus reducing emissions of pollutants to the environment created from the power plants.

Key elements of the HEMS are the smart appliances. In this work, it has been mentioned the main features and benefits to end-user in aspects such as comfort, safety, energy saving and energy management.

Smart appliances integrate cutting-edge electronic modules that allow them to perform functions such as measurement, control and communication, through which they can continuously monitor their energy consumption in order to generate information with which the user can make decisions on a more dynamic and efficient use of energy. The benefit of savings is achieved in the household economy as well as that of the electrical infrastructure of the company supplying the service, and better yet, the benefit of the environment.

The measurement functions of electrical parameters of smart appliances, enable real-time information of the voltage variations on power supply network and thus contribute to electronics

appliance to carry out preventive control actions such as blocking the firing of certain functions that may jeopardize the integrity of the user or the machine itself, or in extreme cases can disconnect the appliance from the network until the conditions of supply of the service is fully restored.

The communication functions are of great importance for the smart appliance, which allows communicating remotely with the In Home Display to read some data or to control the operational status of equipment, knowing information consumption and energy costs, to get alarms in case of operational disturbances or appliances failures or at the electrical grid. It also serves to allow remote programming of the operating modes of the appliance.

The management system of electricity being reported is prepared to transfer information from smart appliances to systems outside of the home through the In Home Display. For example, data can be transferred to the utility's control center through the AMI communication network of the smart grid, sending and receiving messages such as scheduled outages, billing notifications, warnings of low or high voltage grid, and so on. This ability to communicate outside of energy management system also enables the implementation of active control concepts on the demand side.

Results obtained in laboratory test indicated that the information recorded by each appliance, could be helpful for the consumer to save energy and money, as they will know which appliance consumes more energy at home.

With respect to future works, the next stage is test the system in a real environment, i.e. install multiple systems in homes to assess their behavior, so as to verify if it helps to reduce consumption in a home. For that, a pilot project will carry out.

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