http://dx.doi.org/10.5755/j01.eee.19.7.5164 ELEKTRONIKA IR ELEKTROTECHNIKA, ISSN 1392-1215, VOL. 19, NO. 7, 2013

Local Energy Management Unit for Residential Applications

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***Abstract*—Along the coming years, an important increase of the energy consumption in the world is expected, what will lead the energy sector to deal with several challenges such us availability of delivering the demanded energy, increase of the emissions and greenhouse effect. Energy Management Systems are being integrated with domestic and residential applications, which optimize the home energy consumption. The Local Energy Management Unit is presented in this paper that allows an optimized power demand to the Grid. It utilizes different types of communication (by using TCP and X10 protocols) with the aim of obtaining an efficient energy management and allowing a lower power consumption, which lets the user to decrease the cost of the electric invoice. A prototype has been built that shows energy management results. The power demanded from the Grid is kept constant regardless of the house power consumption.**

***Index Terms*—Electric energy management systems, energy storage, intelligent systems, smart grids.**

I. INTRODUCTION

According to the trend along the last years, it is expected an important increase of the energy consumption in the world along the coming years. In fact, the International Energy Agency predicts that world primary energy consumption will increase from 2008 to 2035 by 36% [1]. This mentioned increase will lead the energy sector to deal with several challenges such us availability of delivering the demanded energy, increase of the emissions and greenhouse effect. The international community is supporting the use of renewable [2] and efficient energy sources and a consumed energy optimization. An example is the European "20-20-20" targets [3], which is a set of binding legislation which aims to ensure the European Union meets its ambitious climate and energy targets for 2020: a 20% reduction in EU greenhouse gas emissions from 1990 levels, raising the share of EU energy consumption produced from renewable resources to 20%, and a 20% improvement in the EU's energy efficiency.

The electric Grid is evolving into the Smart Grid, which improves the energy efficiency and manageability of available resources. In addition, Energy Management Systems (EMS) are being integrated with domestic and residential applications, which optimize the home energy consumption. Different EMSs have being studied and proposed [4] which allows a bidirectional communication between energy providers and consumers and provide consumers with information about their energy consumption patterns and help them to adopt efficient energy behaviour. There are some commercial solutions that exist on the market, and the Home Energy Management System by Panasonic is an example, as shown in Fig. 1, which coordinates generation and storage and whose aim is to smooth the consuming curve or even control consume of the energy depending on its price-by-hour [5].

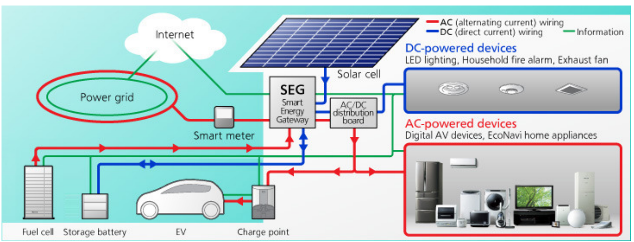

Fig. 1. Home Energy Management System (HEMS) implemented by Panasonic.

This paper refers to the project INTELEM (Intelligent Energy Management System). It takes the advantages of the internet connection most of the houses have in order to coordinate the energy and power consumption of several users, trying to optimize the overall efficiency and the use of the Distribution Grid infrastructures. This system is based on several Local Energy Management Units (LEMUs) that are coordinated by a Central Energy Management and Intelligent System (CEMIS). The CEMIS carries out the coordination after receiving and analyzing the data from the LEMUs using behavioural and intelligent algorithms, and it is being developed under the IntelliDomo project.

This paper will focus on the LEMU. In Section II, the LEMU is presented through the system description and its communication systems. Section III offers an explanation about the energy management system of the LEMU. And finally some conclusions are presented in Section IV.

Manuscript received January 9, 2013; accepted May 3, 2013.
This research was supported by "Ministerio de Economía y Competitividad", "Fondos FEDER", "Junta de Extremadura", "Consejería de Empleo, Empresa e Innovación" and "Fondo Social Europeo".

II. LOCAL ENERGY MANAGEMENT UNIT

The different Local Energy Management Unit's (LEMU's) are placed in houses or residential buildings, as shown in Fig. 2.

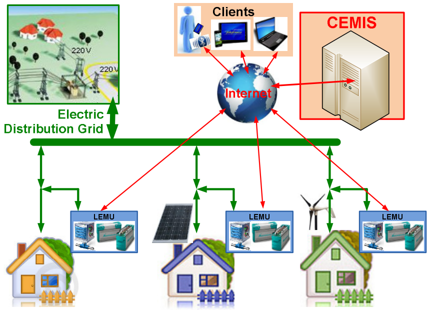

Fig. 2. Schematic description of the INTELEM in the Electric Grid.

The aim of the LEMU is to control the electric consume curve of its corresponding home, and is connected as shown in Fig. 3. It is connected to the Distribution Grid, from which the house and the LEMU obtain the energy. The LEMU is communicated with the CEMIS using TCP/IP protocol (through Ethernet connection), with the different devices of the house such as sensors and actuators using X10 protocol (through the Electric Grid network of the house), and with the ESS using digital and analog inputs and outputs ports.

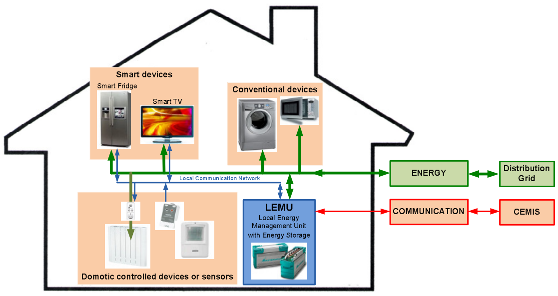

Fig. 3. Location of a LEMU.

The LEMU has three main goals. The first one is to limit the consumption power peaks from the Grid, which occur during the start-up transients or when high power devices operate during short time intervals. This power peaks are delivered by the ESS to the consumer, and therefore the power demanded from the Grid is smoothed. It lets the user to contract a lower power, what, moreover, yields to a decrease in the fixed cost of the electric invoice.

The second goal is to decoupling the energy consumed by the user and the energy demanded from the Grid. The power demanded from the Grid can be smoothed and even become constant, since the ESS stores the power difference between the user consumption and the power demanded from the Grid, (in case the user power consumption is lower than the power demanded from the Grid), or the ESS delivers the power difference (in case the user power consumption is higher than the demanded one from the Grid).

The third goal deals with the connection/disconnection of the different devices under the LEMU control, in order to keep the power consumption under a reference limit. This connection/disconnection of the devices is carried out according to the commands sent by the CEMIS, using the X10 protocol.

A. *Description*

A schematic of a LEMU hardware is represented in Fig. 4. The LEMU is integrated into an energy management network.

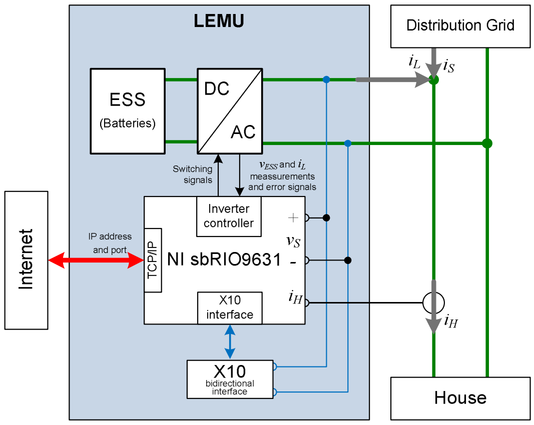

Fig. 4. Schematic diagram of the LEMU with an Energy Storage System.

The elements that make up the LEMU are the NI sbRIO9631, the X10 bidirectional module, the TCP/IP connection, the energy management connection with the ESS charger and the Grid connection. The sbRIO9631 implements its function using the FPGA and the processor. The FPGA is in charge of processing the X10 events, monitoring the ESS charger parameters, obtaining the consumed power and reporting all the information to the CEMIS. The processor is in charge of the Ethernet communication since there are developed libraries for this aim and the Ethernet communication port is associated to the processor and not to the FPGA.

The X10 bidirectional module is a modulator/demodulator that raises the frequency of the signals, in order to be able to send them through the electric Grid network of the house to the different sensors and actuators and control them. It can send and receive signals from these devices.

The Ethernet port (using TCP/IP protocol) allows the communication with the CEMIS. If the connection is lost, the LEMU disconnects a list of actuators due to safety reasons. The inputs are the different X10 commands of on/off or regulation level that the LEMU has to send to the different devices of the house. The outputs are the report of the X10 events that were sent by the devices and the State of Charge (SOC %) of the ESS, which are sent when the events occur, and the power consumption of the user, which is sent every 5 seconds.

The charger is in charge of delivering energy to the ESS from the Grid or demanding energy from the ESS in order to deliver it to the user. The sbRIO9631 reads analog parameters such as Grid, bus and ESS voltages, and Grid and ESS currents. It sends to the charger digital signals (switching signals for controlling the charger).

B. *X10 communication*

The X10 communication flow is shown in Fig. 5.

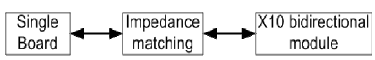

Fig. 5. X10 communication flow.

The X10 bidirectional module has three digital signals, the transmission, reception and the zero cross signals.

There are four codes: the 4 bits Start Code (SC), the 4 bits House Code (HC), the 5 bits Unit Code (UC) and the 5 bits Command Code (CC). SC is the code that allows the system to know the start of the message, HC defines the house that has to read the message or that sends it, UC is the device in the house that has to execute the command or report the event, and CC is the command to be executed.

Transmission process: The information flow goes from the single-board to the X10 module. Each bit is sent each electric Grid signal zero cross and is kept for 1ms. The number of bits is counted in order to know when the process is finished and the whole algorithm is executed every 10μseconds. The sent code is shown in Fig. 6.

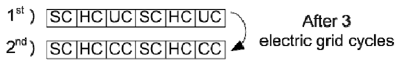

Fig. 6. X10 transmission process.

HC, UC and CC binary codes are sent intertwined with its opposite code and an example for a HC is shown in Fig. 7.

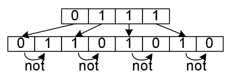

Fig. 7. Example of the HC format sent in a transmission process.

Reception process: The information flow goes from the X10 module to the single-board. Each zero cross electric Grid signal a new bit is stored in a shift register. The information is sent without intertwining (as shown in Fig. 7). The first four bits of the shift register are continuously compared to the SC and when the comparison is true, the reception is right and the CEMIs is reported and the command demanded is executed. Up to now, two different devices are utilized: a lamp (that is turned on and off) and a presence sensor, which reports with an event when a presence is detected.

C. Ethernet communication

Transmission process: The information flow goes from the single-board to the Ethernet port. A Labview virtual instrument ("TCP Open Connnection") is utilized to send the string format messages. Three different codes can be sent, as shown in Fig. 8, the X10 events, the report of the ESS SOC (%), and the user power consumption. The HC code can be from "A" to "P", the UC from "1" to "16", and the CC can be commands such us "light on", "light off", etc.

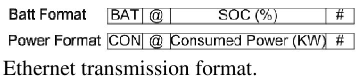

Fig. 8. Message Ethernet transmission format.

Once the message has been received, a "ok" or "incorrect" message is sent back by the CEMIS depending on whether the reception was correct or not, respectively.

Reception process: The LEMU is continuously listening from the Ethernet port with the Labview virtual instrument ("TCP Listen"). When the Ethernet port detects that some message is being received, it is decoded and the command is executed (messages are sent in string format, according to the X10 format shown in Fig. 8).

Once the message has been received, a "ok" or "incorrect" message is sent back to the CEMIS depending on whether the reception was correct or not, respectively.

D. Energy Management System

This subsection is explained in more detail in the Section III.

III. LEMU Energy Management System

The different algorithms that carry out the energy management system are executed by the FPGA.

The difference between the power limit reported by the CEMIs to the LEMU and the user power consumption is stored or delivered by the ESS in order to keep constant and under the limit the power consumption from the Grid.

The ESS is a battery system and a basic topology for the bidirectional battery charging/discharging system is used [6]–[8], as shown in Fig. 9.

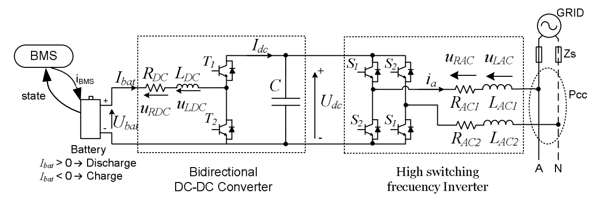

Fig. 9. General electric diagram of the bidirectional battery charger.

The Grid, bus and battery voltages, and the Grid and battery currents are measured by sensors and read through the analog channels. The switching signals for the DC/DC Converter are generated according to Fig. 10, where $P_{reference}$ is the power limit that the CEMIS reports to the LEMU, $V_{s,meas}$ is the measured Grid voltage (V), $i_{H,meas}$ is the current measured in the house (A), $P_{consumed}$ is the power consumed by the user, $P_{Batt,ref}$ is the reference battery voltage (V), $V_{batt,meas}$ is the measured battery voltage (V), $V_{Bus,ref}$ is the reference bus voltage (V), $V_{Bus,meas}$ is the measured bus voltage (V) and $i_{Batt,meas}$ is the measured battery current (A).

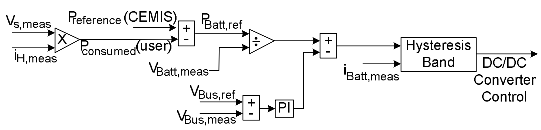

Fig. 10. Generation of the DC/DC converter switching signals.

Fig. 11 shows the AC/DC Converter switching signals generation, where $V_{s,RMS}$ is the RMS Grid voltage value (V), and $i_{s,meas}$ is the measured Grid current (A).

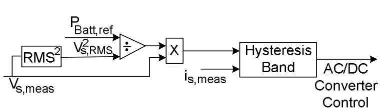

Fig. 11. Generation of the AC/DC converter switching signals.

An example about how the LEMU manages the energy with a 3kWh ESS is shown in Fig. 12.

The LEMU has received a command from the CEMIS to control the demanded power from the Grid below 0.8kW. At the beginning, the user is demanding less than 0.8kW (0.5kW is demanded), and since the demanded power from the Grid is 0.8kW, the remaining demanded power (the difference 0.8kW - 0.5kW = 0.3kW) is stored in the ESS.

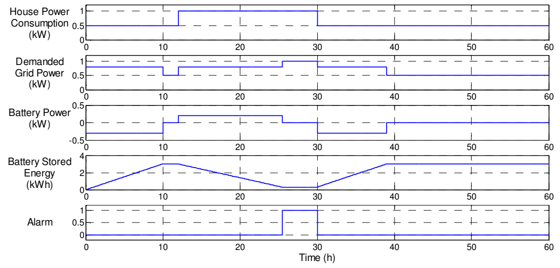

Fig. 12. Example of energy management by the LEMU.

In case the ESS reaches its maximum energy capacity (in this case 3kWh), only the house consumed power is demanded from the Grid (0.5kW). In case the house demanded power is higher than 0.8kW (1kW in the example), the ESS delivers the power difference (0.8kW – 1kW = -0.2kW in the example), and therefore the power demanded from Grid remains constant (0.8kW). This situation could be maintained until the ESS reaches the low energy value, activating in this case the corresponding alarm and disabling the LEMU power control operation. Finally, when the house consumption is again lower than the maximum power reference (0.8kW), the LEMU starts to charge the ESS again.

A prototype of the system has been implemented in order to obtain experimental results. Attending to the battery charger, the battery utilized is the "VHT F – Saft" (10 batteries in series) with a nominal voltage of 12V and 10Ah, a RMS Grid Voltage of 30V, Grid frequency of 50Hz, bus voltage of 40V, each Lac of 28mH, Ldc of 40mH and a switching frequency of 10kHz.

The power demanded to the Grid is constant and 90W.

In case the power consumed by the laboratory is higher than the maximum established power consumed to the Grid, the power difference is delivered by the battery, in order to keep the power consumed to the Grid under the limit, as shown in Fig. 13.

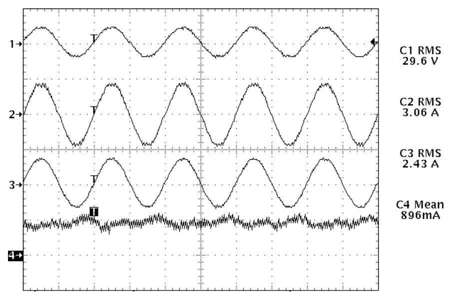

Fig. 13. From top to bottom, Grid voltage and current, and consumed by the user and battery currents, respectively. Consumed power higher than the maximum established power.

Fig. 13 shows from top to bottom the Grid voltage and current, and the battery voltage and current, in case the power demanded by the laboratory is higher than the maximum power established.

In case the power consumed by the laboratory is lower than the maximum established power consumed to the Grid, the power difference is injected into the battery, in order to keep the power consumed to the Grid under the limit, and store energy for any moment in which the battery energy is needed. This case is shown in Fig. 14.

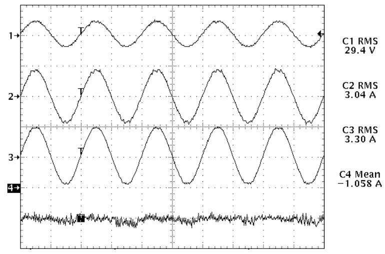

Fig. 14. From top to bottom, Grid voltage and current, and consumed by the user and battery currents, respectively. Consumed power lower than the maximum established power.

Fig. 14 shows from top to bottom the Grid voltage and current, and the battery voltage and current, in case the power demanded is lower than the maximum established power.

IV. CONCLUSIONS

The features and the functions of the Local Energy Management Unit have been presented. Its main function is to efficiently manage the user energy consumption demanded to the Grid, absorbing or delivering energy from the ESS according the residential consumption. In addition, this unit can be communicated with a central server, through the Ethernet port, by using the TCP protocol, and communicated with the different devices of the managed residential area by using X10 protocol for domotic environment. In the paper, it is shown in the presented experimental results, obtained from a built prototype, how the system demands a constant power to the Grid regardless of the consumed laboratory power, and how the demanded currents from the Grid are sinusoidal and in phase with the Grid voltage.

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