ELECTRICITY CONSUMPTION ANALYSIS & ENERGY EFFICIENCY
www.elecon.ipp.pt

Regulatory context of smart grids in Europe and Brazil: current state and trends
Third ELECON Workshop

University of Grenoble Alps – Grenoble Polytechnic Institute, Grenoble, France, November 17-18, 2015.

Power-line communication for equipment control and monitoring in a Smart House context

Jorge Tavares[a], Luis Gomes[a], Kelly Duarte[b], Marco Silva[a], Zita Vale[a], Rubipiara Cavalcante Fernandes[b], Samuel Abreu[b]

[a]*GECAD – Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development, Institute of Engineering – Polytechnic of Porto (ISEP/IPP), Rua Dr. António Bernardino de Almeida, 431, 4200-072 Porto, Portugal*
[b] *Federal Institute of Santa Catarina – IFSC - DAE / Centro - Florianopolis - SC – Brazil, CEP 88020-300*

Abstract

The last changes in the power systems made possible the integration of new concepts and agents in the electrical distributed network. Concepts, such as, smart grids, microgrids and smart houses will have big roles in the future of power systems. This paper demonstrated the use of devices to be implemented in smart houses for monitoring and controlling of resources/equipment. The adoption of this kind of devices are necessary in order to produce autonomous response for demand response events. One of the main problems regarding the integration of monitoring and controlling devices are the installation of the device that can imply wiring installation. The use of power-line communications in electrical resources brings highly advantages, using the existing cables in a simples an easier way. This paper propose a device for controlling and monitoring electrical resources. The paper presents a real installation of this device in GECAD laboratories for monitoring and control the ceiling lights.

Keywords: Energy resources, house management system, power-line communication.

1. Introduction

In the last years the smart grid concept has been introduced in scientific community, this concept brings clear advantages for the distribution network and players (from the market to

the end-user) [1][2]. The application of smart grids opens the opportunity for new concepts and technologies, such as, microgrids, smart meters and smart houses [3]. This paper will focus on the smart house concept and the interaction between the loads and the house management system.

The application of smart houses inside smart grid environments is a key step for success [4]. Some basic features are integrated audio and video, light control, heating control and cooling, security, entertainment and many more [5]. The users living in a smart house can manage and monitor their appliances, giving a better understanding of the energy use. The ability to manage and control equipment (especially loads and storage units) enables the automatic participation in Demand Response (DR) programs [6]. The use of DR programs is very important in a smart grid, these programs can reduce and/or shift the consumption peak demand [7]. Small and medium consumers can participate in DR programs, directly or using a service aggregator.

Smart home technology gives a totally different flexibility and functionality than does conventional installations and environmental control systems, because of the programming, the integration and the units reacting on messages submitted through network [5]. The integration of resources (loads and generation equipment) in a smart house can be done: using new equipment that already have integration capabilities (control and communication protocols); or retrofitting old equipment enabling their control and monitoring. For this paper, it will be used old equipment that will be adapted to integrate a smart house management system.

This paper is organizes as follows. After the initial introductory section, Section II will present SOICAM system. Section III will present the monitor device developed for this work. Section IV will present the results obtain. The most important conclusions of the work are presents in Section V.

2. SOICAM System

The SCADA Office Intelligent Context Awareness Management (SOICAM) was developed by Research Group on Intelligent Engineering and Computing for Advanced Innovation and Development (GECAD) and is implemented in two buildings of GECAD R&D group. The system was developed and implemented to monitor and control the installations [8]. SOICAM system is composed by two layers: the infrastructure layer that enables the integration of real equipment and building; and the operational layer represented by a computational agent that controls and manages the infrastructure using forecasting, optimization and scheduling algorithms for user support.

The two building used in SOICAM had more than 30 researchers working daily. One of the buildings have a 7.5 kW photovoltaic generation capability, this power is injected to the main grid. The monitor and control of the buildings are made with a total of 6 energy analyzers with RS-485 connection, 1 energy analyzer with Ethernet connection and 1 Programmable Logic Controller. One of the buildings have 1 energy analyzer connected through RS-485 with the energy analyzer with Ethernet connection, this configuration enables the outside communication without the need of a Programmable Logic Controller, or any other centralizer. The other building has 5 energy analyzers connected, through RS-485, with the Power-Line Communication - PLC (Figure 1) [9]. The energy analyzers used have an auxiliary port for control, these ports are connected to a relay and a step relay that allow the on/off control of the air conditioners.

At the present moment, SOICAM system operates with energy analyzers that measure and control sections of the building (never less than 3 offices per energy analyzer). This can be a limitation for the application of a more detailed and precise load monitoring and control.

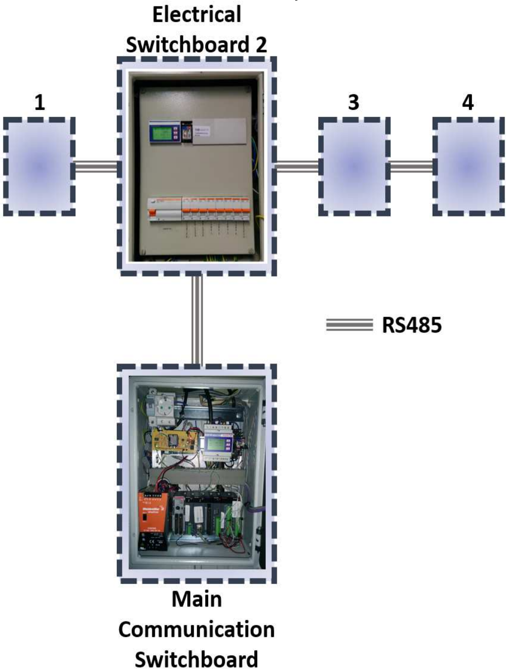

Figure 1. Partial Eletrical Switchboard of SOICAM.

The next step for the SOICAM system is to control and manage the laboratories using individual control and monitoring. The individual control and monitor will bring a better understanding of the consumption loads and will allow a more suitable approach for the optimization algorithms that need to be executed during DR events.

In the past, it was executed a test for individual control and monitor of the refrigerator and the advantages were clear [10]. The interesting results of the refrigerator give us the motivation to prosecute an individual monitoring and control of more and more devices. For the refrigerator control and monitor is used the device of Figure 2. The device is able to turn on and off the refrigerator, read the real-time consumption, measure the inside temperature and measure the outside temperature. The developed device use ZigBee communication protocol and provide us with more than 1 reading per minute (i.e. consumption, inside temperature and outside temperature).

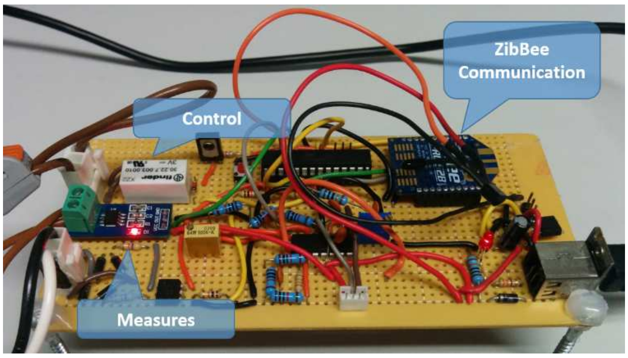

Figure 2. Refrigerator board.

3. Monitor and Control Device

The device described in this paper use PLC in order to reutilize the energy cables that power the load. The PLC was developed from scratch taking into account the final implementation. The retrofitting of equipment can be time-consuming and expensive. One of the biggest problems is the installation of unnecessary wires for communication. PLC uses the existing power cables of the house, not been necessary the new installation of communication cables.

The device communication is separated by two circuits, one transceiver and one receiver. The transceiver is responsible for transforming a high frequency analog signal in a modulated sinusoidal signal composed with the digital information that we want to send. The transceiver is connected directly to 230 V/AC. The development of a transceiver must consider the following modules: a Colpitts oscillator; a common collector amplifier; one ASK modulator; and a signal transformer for the 230 V/AC network interface. Figure 3 shows the electrical schematic of the developed circuit.

The blue area of Figure 3 shows the Colpitts oscillator, this circuit generates a high frequency analog signal that will be carrier wave of the information signal. The high frequency analog signal then passes to the common collector amplifier (green area), which has a low output impedance and a high current gain. The signal is then modulated using a ASK modulator (yellow area) and sent to the electrical house network using a signal transformer (red area).

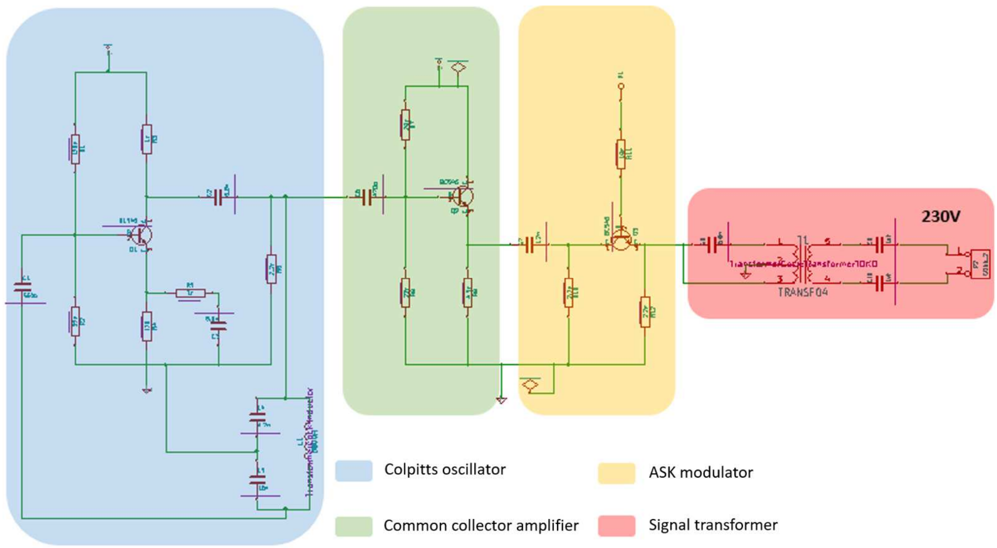

Figure 3. Transceiver eletrical circuit

The job of the receiver is to transform the modulated sinusoidal signal, received from the 230 V/AC network, into a demodulated digital signal. The modules of the receiver are: a signal transformer; a common emitter amplifier; passive filters; one ASK demodulator; and a voltage comparator. Figure 4 shows the electrical schematic of the receiver.

The signal of electrical house network is received using a signal transformer (red area of Figure 4). The signal is then amplified using a common emitter amplifier, represented in yellow area. At this point, the signal has a lot of noise originated from the electrical house network. The green area of Figure 4 shows multiple filters capable of cleaning the signal to a point where is possible to retrieve the maximum amplitude of signal. Then is applied an ASK demodulator on the signal (blue area). The demodulator signal is sent to a voltage comparator (purple area) that analysis two signals and outputs the larger signal. At this moment, the circuit had the original signal with the sent information.

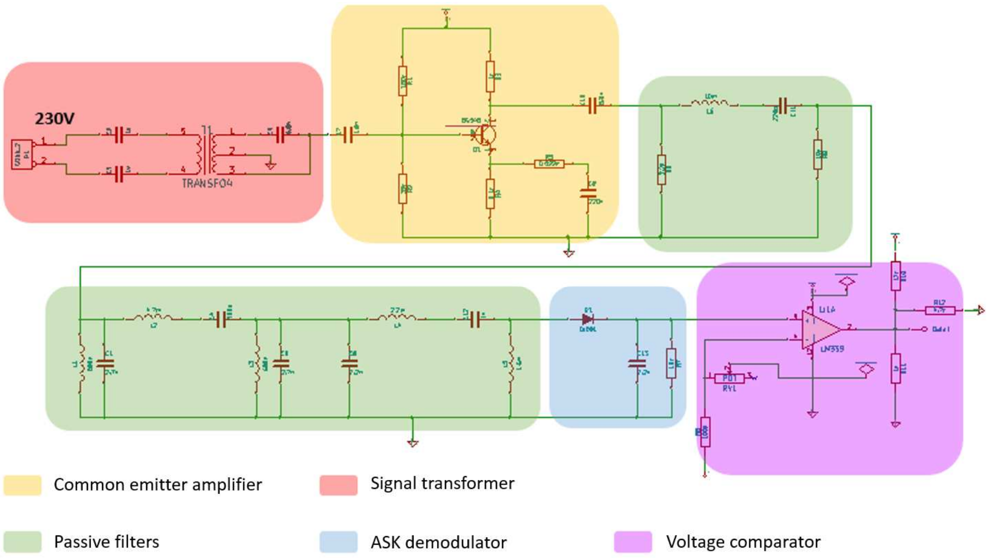

Figure 4. Receiver eletrical circuit.

The device communications packages use Check Redundancy Cycle (CRC) algorithm for package validation, preventing data damage. The size of the package is the size of the information to send plus two additional bytes for the CRC code. The CRC is validated in the receiver and only messages with a valid CRC are processed by the system.

Figure 5 shows the result of the communication tests using the circuits above. The blue signal is the data that we sent to the PLC, while the green signal is received data. The signals are similar enough to be interpreted by a microcontroller. Is possible to see gap between signals created by the signal modulation, transportation and demodulation.

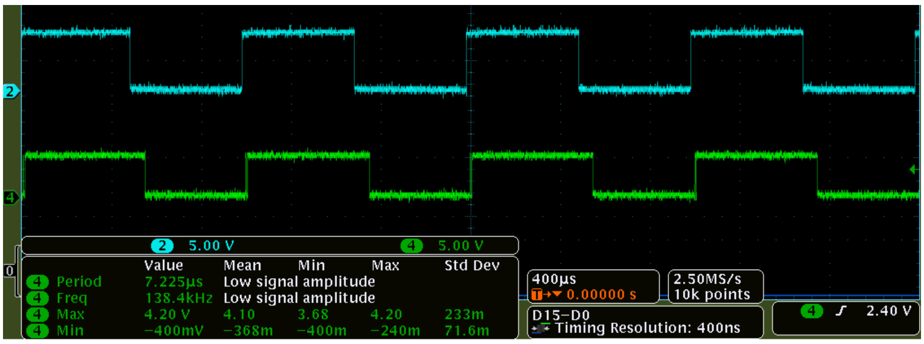

Figure 5. Communication test.

The device developed works with an Arduíno Mega. This Arduíno can connect to energy analyzers using RS-485 communication with Modbus/RTU protocol, and/or control devices.

GECAD laboratories have controllable ceiling lights and controllable window blinds. The device can connect to these loads and acquire control over them.

4. Case Studies

GECAD laboratory ceiling lights are used for this case study, the device will control the ceiling lights and monitor the consumptions of the lights. The laboratory has 5 controlled ceiling lights that can be individually turned on, dimmer adjustable and turned off. The case study will use an energy analyzer for consumption measuring. The device use RS-485 communication, with Modbus/RTU protocol, for the communication with the energy analyzer.

It was used two devices for this case study: one master that sends the commands and receive the consumption information; and one slave device that execute the commands sent, measure the consumption and send back the consumptions. For this paper it was used two Arduíno Mega with PLC, one for the transceiver and other for the receiver. It was putted 5 on/off switches and 5 potentiometers connected to the master microcontroller. The switches can control each individual light while the potentiometers can control the dimmer of each light. Figure 6 shows the communication frame used in this work. After the starting byte the information send are the state of each potentiometer. The second part of the message has the state of each switch. The receiver device is connected to 5 relays (5 V to 230 V) and an amplifier for the dimmer (amplifying a signal from 0-5 V to 0-10 V).

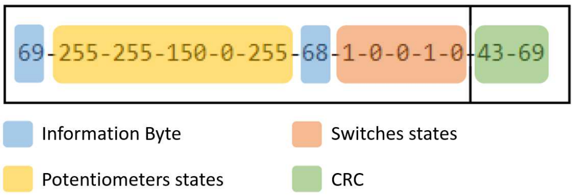

Figure 6. Communication frame.

The frame is sent from the master to the slave every time there are any changes in the states (switches and potentiometers). The consumption are sent once each four seconds from the slave to the master. For this case study was define some actions to be executed in the switches and potentiometers in order to report the system reaction. Figure 7 shows the impact of the lights. In scenario A all the lamps are on using the lower dimmer (0 V), in scenario B the dimmer are at the middle value (5 V), in scenario C the lights have the maximum dimmer (10 V).

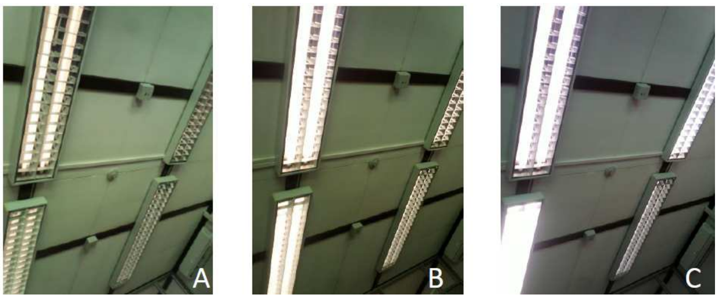

Figure 7. Laboratory ceiling lights.

Figure 8 shows the real-time consumption read from the energy analyser and sent to the

master device. On the chart there are indication of the executed actions during the case study. Each action has its own impact in the consumption of the lights. When the switches are turned on (On Sw*x*) the consumption increases. The changing of the dimmers are made for the 5 lights together and had a big impact on the consumption, putting the consumption under 200 W. The actions and the consumption have some delays that happen because of the communication delay or even because missing data in the frames (bad CRC in the side of the slave).

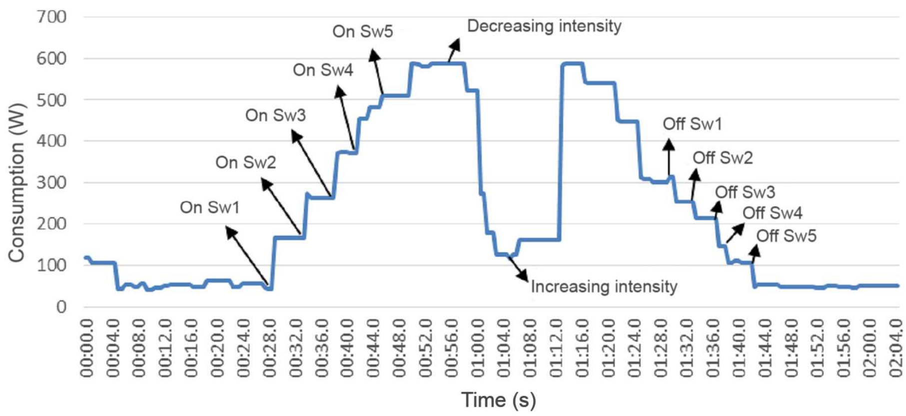

Figure 8. Ceiling lights real-time consumption.

5. Conclusions

This work presents a device for equipment monitoring and control in a smart house context. The device presented uses power-line communication in order to use the existing cables. The use of power-line communications brings clear advantages for retrofitting. The paper describes the developed device and validate the proposed device in SOICAM system. The case studies of this paper shows the successful operation of power-line communications in laboratory. The develop device allows real-time consumption monitoring and load control.

The main contribution of this paper is the proof of concept of the developed device using real laboratories. The work presented has clear advantages comparing to the normal wireless communications, power-line communications can be used in closed rooms with thick walls. As disadvantage, power-line communications have problems working in an unstable power network (i.e. situations with a lot of noise and distortion).

Acknowledgements

The research leading to these results has received funding from the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7/2007-2013/ under project ELECON - Electricity Consumption Analysis to Promote Energy Efficiency Considering Demand Response and Non-technical Losses, REA grant agreement No 318912.

References

[1] C. Clastres, “Smart grids: Another step towards competition, energy security and climate change objectives,” Energy Policy, vol. 39, no. 9, 2011.

[2] V.C. Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, G.P. Hancke, "Smart Grid Technologies: Communication Technologies and Standards," in Industrial Informatics, IEEE Transactions on, vol.7, no.4, pp.529-539, Nov. 2011.

[3] T. Hammerschmidt, A. Gaul, J. Schneider, “Smart Grids are the efficient base for future energy applications,” CIRED Workshop 2010: Sustainable Distribution Asset Management & Financing, Lyon, France, 7-8 June 2010.

[4] K. Kok, S. Karnouskos, D. Nestle, A. Dimeas, A. Weidlich, C. Warmer, P. Strauss, B. Buchholz, S. Drenkard, N. Hatziargyriou, V. Lioliou, "Smart houses for a smart grid," in Electricity Distribution - Part 1, 2009. CIRED 2009. 20th International Conference and Exhibition on , vol., no., pp.1-4, 8-11 June 2009.

[5] S. Madakam, R. Ramaswamy, "Smart Homes (Conceptual Views)," in Computational and Business Intelligence (ISCBI), 2014 2nd International Symposium on, pp.63-66, 7-8 Dec. 2014.

[6] H. Morais, Z. Vale, T. Pinto, L. Gomes, F. Fernandes, P. Oliveira, C. Ramos, "Multi-Agent based Smart Grid management and simulation: Situation awareness and learning in a test bed with simulated and real installations and players," in Power and Energy Society General Meeting (PES), 2013 IEEE, pp.1-5, 21-25 July 2013.

[7] B. Morvaj, L. Lugaric, S. Krajcar, "Demonstrating smart buildings and smart grid features in a smart energy city," Energetics (IYCE), Proceedings of the 2011 3rd International Youth Conference on 7-9 July 2011.

[8] L. Gomes, F. Fernandes, P. Faria, M. Silva, Z. Vale, C. Ramos, "Contextual and environmental awareness laboratory for energy consumption management," in Power Systems Conference (PSC), 2015 Clemson University , vol., no., pp.1-6, 10-13 March 2015.

[9] P. Kühne, I. Hauer, Z. A. Styczynsky, R. Fernandes, Z. Vale, “Smart Grid Communication Technologies In The Brazilian Electrical Sector,” First ELECON Workshop – Towards Efficient European and Brazilian Electricity Markets, Porto, Portugal, 24-25 Sept. 2013.

[10] L. Gomes, H. Amaral, F. Fernandes, P. Faria, Z. Vale, C. Ramos, A. Souza, “Dynamic Approach and Testbed for Small and Medium Players Simulation in Smart Grid Environments,” 19th World Congress of the International Federation of Automatic Control (IFAC 2014), Cape Town, South Africa, 24 – 29 Aug. 2014.