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Design and implementation of a power quality monitoring system over internet

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Abstract –

In order to raise awareness about energy waste, an energy monitoring system able to be used either in residential or commercial applications is proposed in this paper. The acquisition system is based on Arduino Due (ArD), X-Bee and free software. The system has been designed considering low-power consumption and low-component count while meeting international standards. The prototype is constituted by a signal conditioning circuit capable to conditioning up to 8 channels (4 for voltage and 4 for current) and an Arduino Due capable to acquire 8 channels simultaneously. The prototype was tested at a laboratory and in an residential application, an evidence of its performance is given.

I. INTRODUCTION

An increase of 93% in the electricity generation has been estimated by 2040 (from 20.2 trillion kWh in 2010 to 39.0 trillion kWh in 2040) [1]. Is expected that world wide electricity delivered to end users rises by 2.2% per year from 2010 to 2040, as compared with average growth of 1.4 % per year for all delivered energy sources. On the other hand, environment issues and scarcity of the natural resources, influence public policies of energy consumption towards of energy utilization improvement. Saving energy, reducing environmental pollution and performing a rational use of the energy have become important issues for most countries. An approach to get a rational use of the energy, is to create awareness among consumers about their electrical energy consumption profile, as well as, monitoring continuously the supplied energy to detect energy losing and optimize its consumption [2].

Research has shown that the residential energy consumers waste almost 41% of the power supplied to their homes [3]. In 2013, the residential sector in Mexico consumed 238 PJ of energy (66113 GWh). Managing the energy consumption of this sector is an important priority for addressing global warming problems, conserving resources and improving energy security. This sector represents 25.4% of national energy demand, compared with a 24.85 % demanded in 2003 [4]. A substantial portion of energy consumed in a house is used to deliver energy to applications not actually needed by residents (e.g. heating, ventilating and air conditioning systems, computers, cellular chargers, TVs) while residents are outside their house [2].

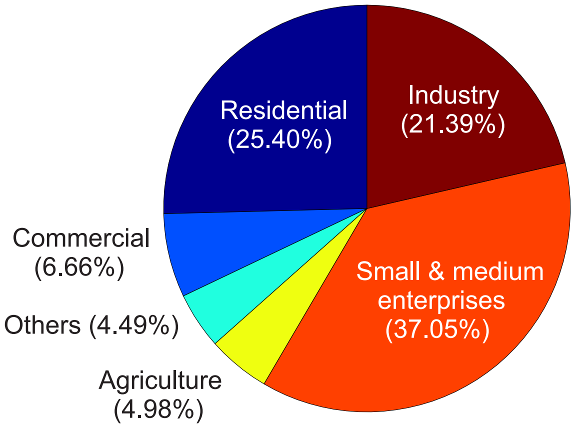

Fig. 1. Distribution of energy consumption in Mexico in 2013.

In some countries, electric energy is subsidized by government. People do not pay the total amount of consumed energy in their houses; sometimes this fact lead to energy waste. Thus, it is important to carry out an economic energy power consumption monitoring to created awareness in the people and avoid energy waste. If consumers take into account their electrical consumption profile to take corrective actions that can reduce losses, an optimized energy consumption can become possible.

Different power quality monitoring systems has been proposed in the literature [5]-[10] among others. The development of an electric power quality monitor is presented in [5]. The monitor is constituted by four current sensors and another four for voltage sensing, the graphical user interphase (GUI) is based on LabVIEW. The monitor can function as a digital scope, analyze harmonic content, detect and record voltage disturbances, among others. In [7] an innovative low-cost web-based distributed

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measurement system (DMS) for electrical power monitoring is proposed. The DSM use smart sensors and a PIC microcontroller. Although, these systems use proprietary software (LabVIEW); the application portability to different platforms and operating systems has not been taken into account. By the other hand, the proposed systems do not attempt to raise awareness in the people. A computational tool for managing data from a measurement plant of power parameters is presented in [10]. The developed software (SIGEE) is based on Java SE and the structured database MySQL. SIGEE had as motivation the power networks evaluation with respect to the introduction of smart metering devices, which allow consumers to track their energy consumption and the quality of the supplied power.

In this paper, a wireless power quality monitoring system over internet (WPQMSOI) is proposed. The WPQMSOI makes use of open software and X-Bee architecture to achieve an interoperable energy monitoring system, which is independent of the computing platform, development tool and programming language. The WPQMSOI has the ability to acquire the signals from the AC mains (voltage and current) and send them via wireless communication to a personal computer (PC). Once in the PC, all the acquired signals are sent to a central server were they are further processed and stored. A GUI has been developed to show the acquired data (in both numeric or plot form). The frequency, as well as both the peak and the RMS voltage value can be displayed. Also, phase difference between both signals can be measured and displayed; the active, reactive and apparent power and power factor (PF) are computed and displayed too. The total energy consumption and corresponding cost can be shown by day, week, month and year. We are looking to involve consumers by education on standby energy consumption with the proposed WPQMSOI. It is not an easy task to convince users to adopt some energy efficiency practices, particularly when the saving is not high at individual level. Moreover, the WPQMSOI gives significant help in avoiding electricity-related frauds and create awareness in the energy consumption.

The rest of the paper is organized as follows. Section II describes the overall structure of the WPQMSOI. In Section III, a description of the WPQMSOI implementation is presented. The laboratory tests are shown in Section IV. Section V presents the assessment and evaluation of the platform in a building. Finally, Section VI presents the conclusions of the developed WPQMSOI and future work.

II. ENERGY MONITORING ARCHITECTURE

The WPQMSOI is conformed by hardware and software. A block diagram of the proposed system architecture is shown in Fig. 2. In order to ensure the viability and security of the measurements, a signal conditioning circuit has been built (according to the norm IEC 61000) to measure and to adapt the current and voltage levels from the AC mains into the input levels of the analog-to-digital converter (ADC) of the Arduino Due (ArD). The ArD is the interface between the analogue and the digital signals. The acquired data are administered by the ArD and sent via wireless (X-Bee) to a PC. The data are received by another X-Bee connected via USB port to a PC. The acquired data are stored (for subsequent post processing) and plotted in the PC.

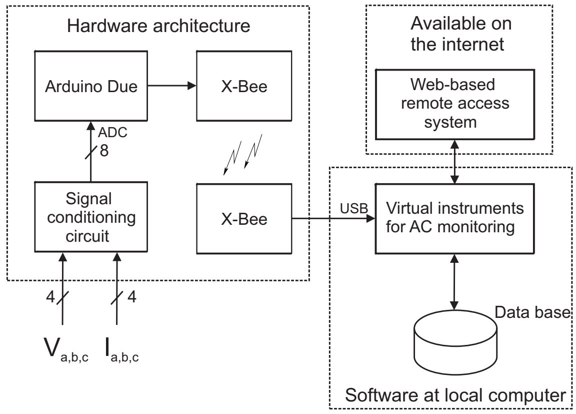

Fig. 2. Proposed system architecture.

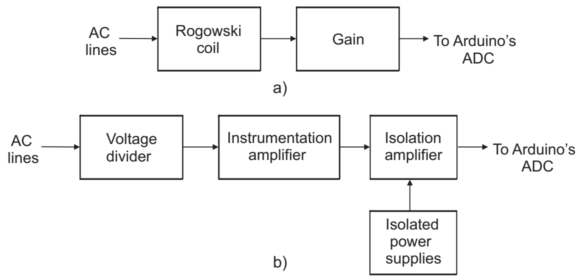

Fig. 3. Signal conditioning block diagram.

A. Hardware

The hardware is constituted by two circuits, one for voltage conditioning and another for current conditioning. Fig. 3 shown a block diagram of each one of these circuits. The current of the AC mains is sensed by a Rowoski sensor (Fluke i2000flex). The i2000flex sensor only measures AC currents with frequencies between 5 Hz to 20 kHz. The sensor allows the measurement of currents up to 2000 A. Since the current sensing is performed by sensing the magnetic field, no isolation is needed; also, it is not necessary to interrupt the circuit to install the sensor.The output voltage of the sensor is amplified to the supported levels of the Arduino's ADC (3.3 V).

The AC mains voltage is sensed by a voltage divider. The AC mains voltage is attenuated to 3 V. Then, it is measured by an instrumentation amplifier. An isolation ampli-

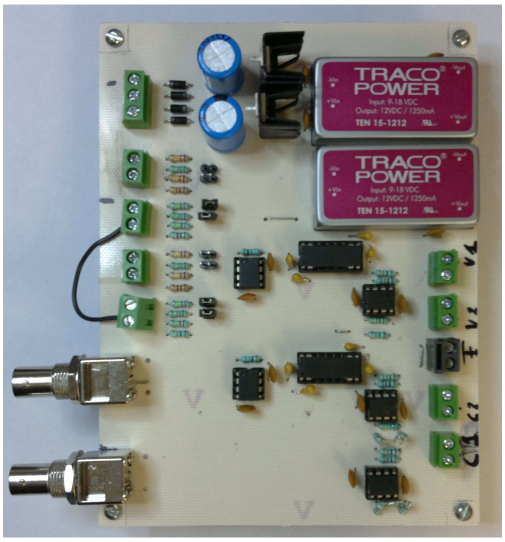

Fig. 4. Signal conditioning circuit.

fier is used to isolate the AC mains voltage from the input of the Arduino's ADC, avoiding any ground loop or the ADC damage in case of a short-circuit. The signal conditioning circuit is shown in Fig. 4. The board shown in Fig. 4 is for two channels, two boards were built, allowing to monitor single to three-phase systems.

Electric-power-system monitoring and diagnostic systems are typically carry out through wired communication. However, due to the defects of complex cabling, troublesome maintenance and high cost [11] wireless technology is selected to send acquired data to a PC. The X-Bee is a wireless communication technology of uniform technical standards in short distances (approximately 30 m indoors). X-Bee technology has advantages such as low-power consumption, low-cost, large network contained short delay time, high safety, low complexity, and working frequency [14]. To administrate the received data by a X-Bee connected to a PC via USB port, a computer application program was developed.

B. *Software*

The software of the WPQMSOI is a web application, developed in Java and the structured database MySQL. The idea behind a web application or dynamic application has been around for some time, usually applied to graphical client-side applications, and is generally known as the Model-View-Controller (MVC) paradigm. As the paradigm suggests the application models the data and control the view of them. Java models the data and gives the interface to the database (DB) interacting with the application via the web.

It is worth noting that the implementation of web application in Java associated with the use of a DB is an approach that can be employed with the aim of promoting, among other benefits: *i)* the application portability to different platforms and operating systems, *ii)* the independence of a proprietary software, such as Matlab, LabVIEW, etc. for making a diagnosis and *iii)* the facilitated handling of measurements recorded in the database.

The developed applications allow the WPQMSOI to function like a digital oscilloscope, the digital data can be analyzed via web application by a PC. After the digital data are transferred to the server, the user can activate the program in the server side to perform the software located at the far side. Analysis results can be displayed through designed GUI.

The conditioned signals are digitized via the Arduino's ADC. The digitized signals are transmitted via X-bee. In the server side, a module written in Java is created to read the data received via X-bee. This module register in the DB the artifact of the power line, write down the signal data and the time stamp of the event. In the client-side, it only needs to get a response from a URL request of the WPQMSOI's server. The communication and coordination between the user and the software can be facilitated through a web application. The Transmission Control Protocol (TCP) is selected to implement the WPQMSOI. TCP is one of the best choices for network applications, because it is reliable and connection-based protocol (sites must establish a connection before transferring data), it provides error detection and ensures that data arrive in order and without duplication; moreover, TCP allows multiple, simultaneous connections.

III. IMPLEMENTATION OF THE PROPOSED SYSTEM

An Arduino Due (ArD) is selected. It is a 32 bits ARM cortex microprocessor, it has one ADC of 12 bits that can be multiplexed to a maximum of 12 input channels. The maximum clock frequency of the ArD is 84 MHz. The ArD is able to perform unipolar conversions, its conversion rate is 6.3μs. If eight channels were used (3 for both current and voltage of each phase and 2 for current and voltage in the neutral), the maximum frequency allowed to be sampled would be 25 kHz (allowing us to calculate the spectrum with more than 512 samples). The ArD nominal power is 2.64 W (3.3 V @ 800 mA).

The developed web application has the following facilities: *i*) the PC server is used to store the monitored data, *ii*) a hard drive is used to store the power quality data, *iii*) internet is used to disseminate the power quality data to concerned engineers and users, *iv*) using web-based system, the user is allowed to access data from existing database with user name and password.

The implemented method in the web-based system follows the three steps. First, to obtain sampled voltages with a certain sampling rate and resolution. For every event, voltage samples are obtained with a sampling rate (established as samples per second or per cycle) and with a resolution determined, stated as the number of bits. Many commercial PQ measurement instruments have sampling rates of 256 samples per cycle, since the majority of PQ events have frequency contents below 5 kHz. The proposed sample rate per cycle of the WPQMSOI is 256; with this sampling rate we can avoid the saturation of the wireless transmition channel and the lose of the acquired data. Secondly, it calculates event features as a function of time from the sampled voltages. This characteristics can include RMS voltages, RMS currents, negative and zero-sequence un-biases, real and reactive power, harmonic distortion levels and individual harmonic components. For three-phase measurements, the three voltages will typically have different characteristics versus time for the three phases. From these three functions additional characteristics are needed.

RMS values of voltage, current and power cannot be calculated by standard formulas due to the discrete area. The calculations of these variables has to be done in discrete time. Equations 1, 2, 3 and 4 shown the way in how these calculations can be carried out.

$$v_{RMS} = \sqrt{\frac{1}{n}\sum_{i=1}^{n} v_i^2} \quad (1)$$

$$S_{discrete} = v_{RMS} i_{RMS} \quad (2)$$

$$P_{discrete} = \frac{1}{n}\sum_{i=1}^{n} v_i i_i \quad (3)$$

$$Q = S - P \quad (4)$$

IV. ASSESSMENT AND EVALUATION

In order to verify the performance of the proposed WPQMSOI; the active, reactive and apparent power and the PF of the Hybrid System Laboratory are measured for an interval of a month.

The WPQMSOI makes energy consumption information and data available to the user. In order to access the data, the user needs to know the site address and have a browser; also the user must know his user name and password to get access to the WPQMSOI. Both recent and historical data can be viewed at any time from any internet connected PC using a web browser. Mainly, the WPQMSOI is tested on a local area network (LAN) of the institute and implemented on internet.

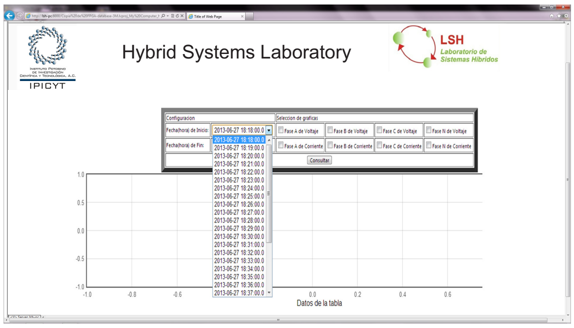

Fig. 5. Screenshot of the WPQMSOI.

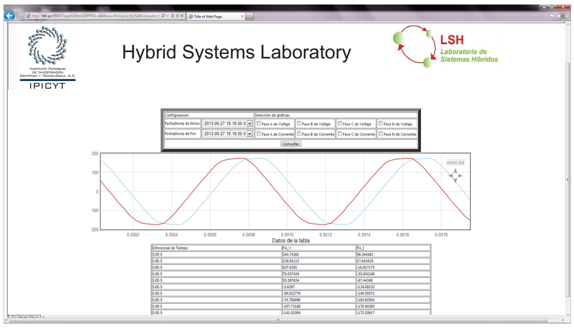

Fig. 6. Screenshot of the WPQMSOI for a two-phase system.

Once the user's access the system, a control panel appears. The control panel has a search module; it allows the user to select the date and time of which the data want to be consulted. Also, the desired phase can be selected, plotted and spread out as a table (see Fig. 5).

Fig. 6 shows a plot of the selected data for a two-phase system. Another screenshot for a three-phase system is shown in Fig. 7. The user can move through the plot and make a zoom.

V. CONCLUSION

The design of a wireless power quality monitoring system over internet has been described. The prototype was tested in a laboratory. It is very easy to install because it uses rogowski sensors; it can monitor loads in the range of 10 W–20 kW. The maximum measurable power and resolution can be selected by changing a resistor value with jumpers. The system was designed and implemented to enable remote access (24h/7) through internet. The advantages of this system are open architecture, easy implementation, user-friendly, low-power consumption, cost and analysis and management platform based on PC re-

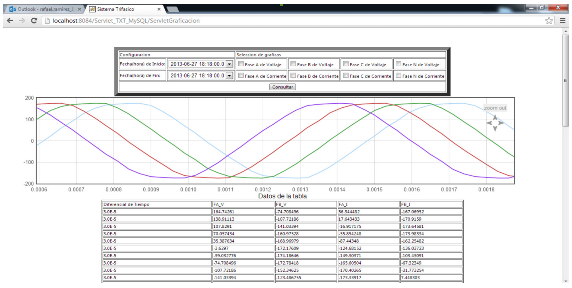

Fig. 7. Screenshot of the WPQMSOI for a three-phase system.

sources. The developed prototype can be used as a powerful didactic tool for student and engineers. Also, it can be extended to other instrumentation and measurement applications such as photovoltaic, battery and fuel cell power systems. Applying different digital signal processing techniques the system could identify sags, swells, spikes, flickers, etc.

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