BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Publicat de
Universitatea Tehnică „Gheorghe Asachi” din Iaşi
Tomul LXI (LXV), Fasc. 4, 2015
Secţia
ELECTROTEHNICĂ. ENERGETICĂ. ELECTRONICĂ

POWER MONITORING SYSTEM BASED ON ADM1191 DEVICE

BY

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Received: November 6, 2015
Accepted for publication: November 23, 2015

Abstract. The problem of achieving energy efficiency by power consumption reduction is a hot topic that interests not only designers of new systems but also engineers seeking to improve the efficiency of legacy systems. Present paper presents a system that can be used to monitor power consumption and if connected over Internet to dedicated cloud services can display in real time the monitored quantities in the system. The monitoring system was tested with a PLC based system and with one based on FPGA. Monitoring system can disconnect parts of monitored system circuits in order to identify power hungry components or for studying the implementation of different power saving modes.

Key words: power monitoring; embedded system; PLCs; IoT; FPGAs.

1. Introduction

PLC based systems have become well established parts of the industrial systems. Products in other areas like home automation, medical equipment and home appliances have been also built using PLCs and taking benefit of their simplicity, robustness and easy to use (Webb & Reis, 2002; Stenerson, 2004).

In recent years there were attempts to replace PLCs with other systems based on new technologies such as industrial PCs, industrial automation controllers or single board controllers but the results were not yet very satisfactory.

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The popularity of PLCs relay on their many advantages among which easy to program, flexibility, upgradability, easy troubleshooting, compactness are the most important (Stenerson, 2004).

Efficient energy management is a very important trend in our days and large efforts are made to reduce the carbon footprint of every system in order to consciously build a future sustainable world (EnergyDesignResources, 2006).

New technologies and new design methodologies are developed where the energy efficiency plays an important role and are taken in to consideration from initial specification up to final implementation. Nevertheless, the rate of replacement of older technologies with the new ones is small especially in most of the industrial sectors where cost of replacement could be very high. Addressing the energy efficiency cannot be postponed too much into the future, we have to analyze the possible solutions that can be applied today for the system in operation.

In PLC based systems energy consumption computation can be done starting with the design stage. The results are used for the selection of number and type of power supplies used in the system. During system lifetime, the configuration can change and so do the components and their characteristics. Monitoring power consumption in such a system can bring important information that can result in system optimization and increasing energy efficiency.

Usually, in such systems, several power supplies are used. One can be used to power the central processing unit (CPU) of the PLC while the others can be used to power the other PLC components (I/O modules, communication modules, specialized modules) organized in racks. External inputs and outputs are usually not supplied from the PLC power supply. In PLCs from the small category though, we can find dedicated terminals that provide supply power for external input and output elements.

In this paper we present a power monitoring system that can be used for power monitoring in order to indentify power consumption models, power hungry consumers, transient and long term erroneous conditions (overcurrent, overvoltage, under voltage). The system was tested with a PLC based system and an FPGA based system. Real time visualization of the monitored data was also possible as the system was connected over the Internet via dedicated cloud services.

2. System Overview

The proposed monitoring system (MS) is given in Fig. 1. The MS is built using a microsystem based on a 32-bit microcontroller which performs processing and controlling activities of the system (ChipKIT^{TM} WF32^{TM}…, 2013).

The other components of the MS system are the Power Monitor module (PMON), the temperature sensor (TMP), the real time clock module (RTCC), Bluetooth module (BT) and an OLED (organic LED) display. These components of the system are connected to the microsystem using available communication interfaces *i.e.* UART (Universal Asynchronous Receiver and Transmitter) for connection with the Bluetooth module, SPI (Serial Peripheral Interface) for connection with the OLED display and I2C (Inter-Integrated Circuit) for connection with the TEMP temperature sensor, the RTCC and the Power Monitor modules.

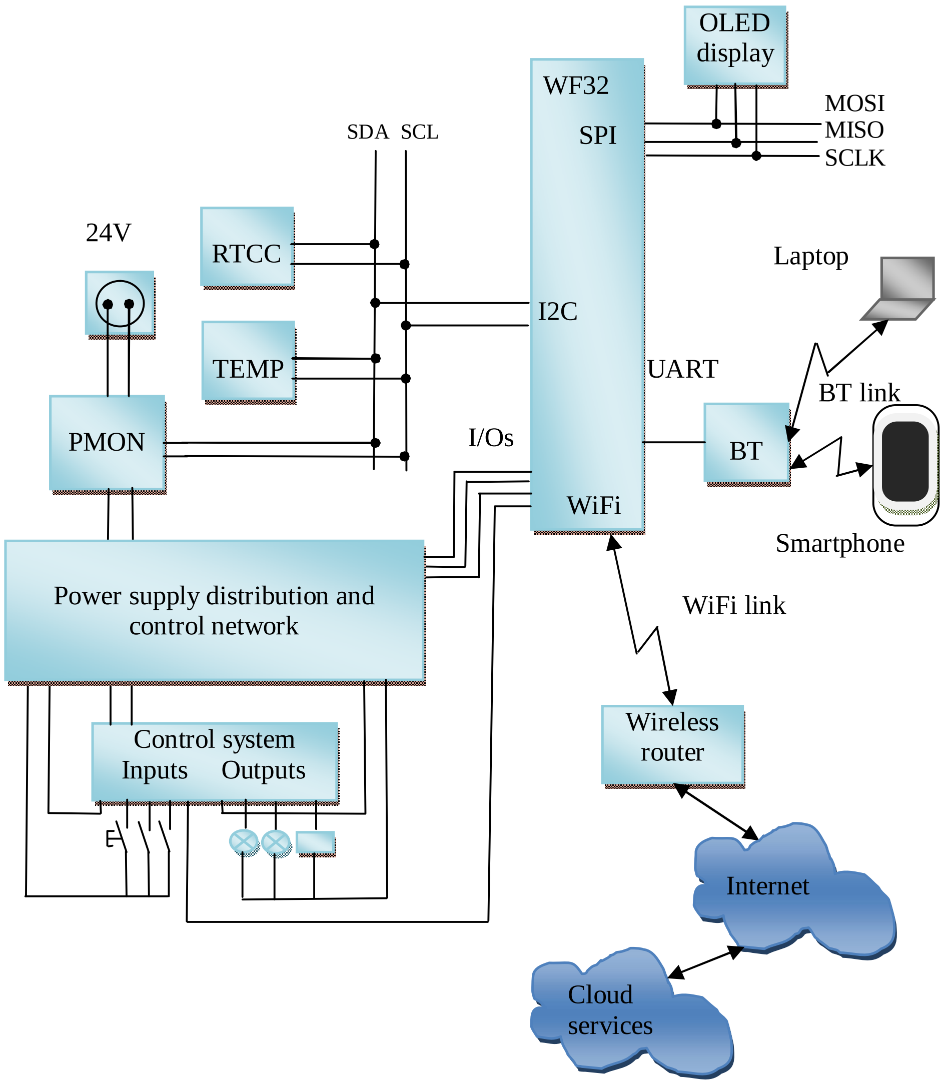


Fig. 1 – Power monitoring block diagram.

The PMON module (PmodPMON1^{TM}…, 2013) produced by Digilent

Inc. is based on Analog Device Digital Power Monitor ADM1191 (Analog Devices, 2006) and the AD5112 digital potentiometer (Analog Devices, 2011).

The Bluetooth module allows connection of MS to a laptop or smartphone.

The microsystem includes an SD card reader that can be used to record data collected from the system. Data is saved in comma or tab separated value format with a time stamp read from the real time clock module. Recorded data can be processed later using Microsoft Excel or other well known data processing software.

MS connection to Internet and cloud services is made using the Wi-Fi module available on the microsystem board and which connects to a wireless router. Data read from MS can be sent to web based applications for storage, processing, sharing, displaying and can be exchanged with other systems in the frame of the Internet of Things (IoT) concept (Gubbi *et al*., 2013).

The MS is connected to the monitored system through a power supply distribution and control network. The network allows the distribution and control (switch on or off) of power supply lines to different components of the monitored system. This allows the MS alone or in conjunction with the control device of the monitored system to connect or disconnect parts of the system in order to study and implement different power saving strategies and also for safety measures.

The microcontroller application was written and tested using the MPIDE development environment from Microchip which mimics the Arduino development environment. The MS microsystem can be connected to the PC using the USB interface allowing the transfer of the microcontroller program and some limited debugging.

3. System Description

In the following section we will detail the structure and operation of system components.

A. *The microsystem*

The MS is based on WF32 board equipped with Microchip PIC32MX695F512L microcontroller (ChipKIT^{TM} WF32^{TM}…, 2013). The microcontroller running at 80 MHz is equipped with: 512 KB Flash memory, 128 KB SRAM memory, I/O pins that give access to USB 2.0 OTG controller, SPI interfaces, UART interfaces, I2C interfaces, 16-bit timer / counters, 10-bit analog inputs etc. The board includes a Microchip MRF24WGOMA Wi-Fi module and a micro SD card connector. These rich set of resources provide the support for all functions that have to be developed for the MS system.

A number of 43 of the I/O pins of the PIC32 microcontroller are accessible from five input/output connectors. Connectors include groups of pins of the same type (digital, analog) and part of the pins (ex. outer rows) corresponds to pins compatible with Arduino boards. This allows the use of a large set of dedicated modules (Arduino shields) which interface the microcontroller with digital inputs and outputs, sensors, actuators, displays or communication integrated circuits (ICs).

The PIC32 microcontroller is loaded with a bootloader which is configured so it can be programmed using Microchip MPIDE programming environment. MPIDE is a programming environment adapted by Microchip from Arduino for its PIC32 32-bit microcontroller family. Along with MPIDE comes a large set of applications and libraries written for Arduino boards which are directly usable in MPIDE while others are written specially for Microchip boards, all freely available on the Internet.

B. *Sensor*

It is well known that temperature increase inside system components can result not only in the reduction of operation life but also in an increase of energy consumption. Existence of a temperature sensor can monitor the temperature in the system relating the increase of energy consumption to this cause.

Actual prototype of the system includes only a temperature sensor that communicates with the microsystem using the I2C interface. The temperature sensor is a Microchip TCN75AVUA device included in PmodTMP3 Digilent module. The resolution of the temperature sensor is programmable from 9 to 12 bit with typical accuracy of ±1° C.

For a more complex system, the MS can be extended with a set of temperature sensors placed in different parts of the system, all sensors connected on the same I2C serial bus (Breniuc & Haba, 2002).

C. *Power Monitor*

Power monitoring is achieved using the PmodPMON1 power monitor module from Digilent Inc. (2013). The module is based on an ADM1191 digital power monitoring circuit (Analog Devices, 2006) and an AD5112 digital potentiometer (Analog Devices, 2011). The potentiometer and power monitoring IC are connected on an I2C bus through which can be configured by the microsystem microcontroller. The wiper of the digital potentiometer is connected to the SETV pin of the power monitoring circuit.

The functionality of the power monitoring module is configurable as a result of various features available for the ADM1191 digital power monitoring circuit. The module can be configured to measure the current, the voltage or both (thus allowing computation of power). Measurements can also be continuous or triggered at certain times and a large set of alert conditions can be set. An internal attenuation network can also be set to change the voltage range from 26.52 V to 6.65 V.

The ADM1191 can be configured to issue alerts either by comparing voltage of a dedicated input pin (SETV) or comparing current measured value with a threshold value stored in the circuit registers. Using the AD5112 digital potentiometer whose output is connected to the SETV pin, the flexibility for configuring the alerts is increased as wiper position and threshold values in ADM1191 registers can be changed during system operation.

Configuration can be done in the microcontroller program or later during operation using an application that runs on a laptop, tablet or smart phone with Bluetooth connectivity. Bluetooth connection is possible using the Digilent PmodBT2 module based on the Roving Networks® RN-42 circuit and can be controlled using the UART interface. The application is used to configure the functionality of the system but can be used as interface for displaying the measured quantities (*i.e.* current, voltage, power and temperature), local time or other information in the system.

D. *Communication*

The MS system can use one wired and two wireless communication channels.

Wired communication is possible using the USB 2.0 controller with A and micro-AB connectors. The USB communication is used for programming the microcontroller of the MS system but USB On-The-Go (OTG) functionality can also be implemented.

The Microchip MRF24WGOMA Wi-Fi module available on the microsystem board is used for mid-range wireless communication. It provides both hardware and firmware support for 802.11b/g compatible Wi-Fi network communication. Control of external interrupt and hibernate signals of the module allow implementation of low power modes for the system by reducing data communication and power consumption of the module.

E. *OLED Display*

Local data display is achieved using a Digilent PmodOLED module that contains a display of 128 × 32 pixel OLED controlled by SSD1306 Solomon Systech chip.

On the screen display will be displayed measured values for monitored parameters (temperature, current, voltage and power), alert information and also other information relevant to system operation (initialization messages, low power supply voltage etc).

F. *External Memory*

Two solutions are most used for local storage of measured data: integrated EEPROM memories with either I2C or SPI interfaces or SD memory cards which are read and written using SPI interface. Main advantage of the EEPROM memory is its small size which is eclipsed by drawbacks like small capacity and immovability (it cannot be removed to be inserted and read by a PC). Removable SD card memories have large capacity of the memory and can be removed to be read by other devices like PCs, tablets or smartphones. Our microsystem board comes with SD card reader on board so it can be used to record different measured or system data.

The MS system is designed to monitor energy consumption and the occurrence of well defined signal events will trigger alerts. These alerts will be used in the system operation but at the same time it is important that relevant ones be recorded for further analysis and processing.

The structure of the recorded data will include a time stamp provided by the real-time clock module (a Digilent PmodRTTC module based on Microchip MCP79410 circuit), measured data and additional information. The records, time stamps, measured data and information will be recorded on the SD card in CVS format.

The user can record different types of events: overvoltages, low voltage, overcurrents, voltage or current steps and power greater than a threshold.

G. *Cloud Platforms*

One of the actual trends in industrial system is to increase their connectivity by augmenting machine to machine and machine to man communication. Exchanging large set of information can improve system observability, controllability and thus its productivity and outputs quality.

The connectivity will go beyond factory floor, linking systems and machines in entirely different geographic locations. This can be achieved using software platforms which are application independent and provide an easy path to build services that facilitate data exchange, processing and control.

A lot of such platforms started to emerge spanning from very simple to the more complex ones. Examples of such platforms that have been tested by the authors are Ubidots, FlowCloud or dweets.io (Semmelhack, 2013).

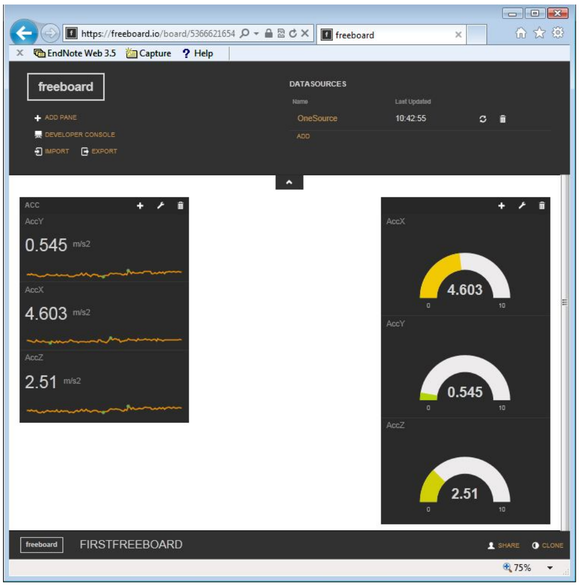


Fig. 2 – Dashboard created in Freeboard platform for monitoring three data streams.

We present the use of dweets.io platform which provides a way of exchanging data between systems connected to internet (called things) using messages called *dweets* in the same way people exchange short information using Twitter *tweets*.

The Freeboard platform can be used to display data exchanged via dweets using very simple dashboards and visualization elements.

In Fig. 2 is presented a screen shot of a dashboard and corresponding visualization elements for three data streams. Recorded data can be displayed in the dashboard in multiple formats (in our case as numerical values, gauges and plots) and can be accessed with any device running a web browser and which is connected to the Internet.

4. Experimental results

The MS was tested using two different systems, one based on PLC and a second one based on FPGA.

The first system is based on a PLC that is receiving inputs from a process or from a human operator and is controlling different loads such as lamps, relays, valves and motors. The MS is monitoring the power supply line using the PmodPMON1 module and has the possibility to disconnect power supply of PLC, input circuitry or output circuitry.

In Fig. 3 are given the details of the Power supply distribution and control network for power monitoring of the PLC based system.

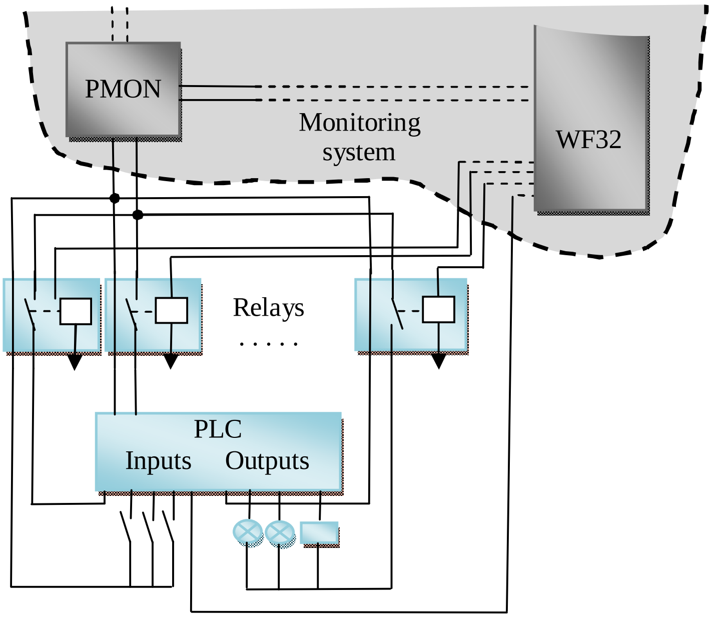
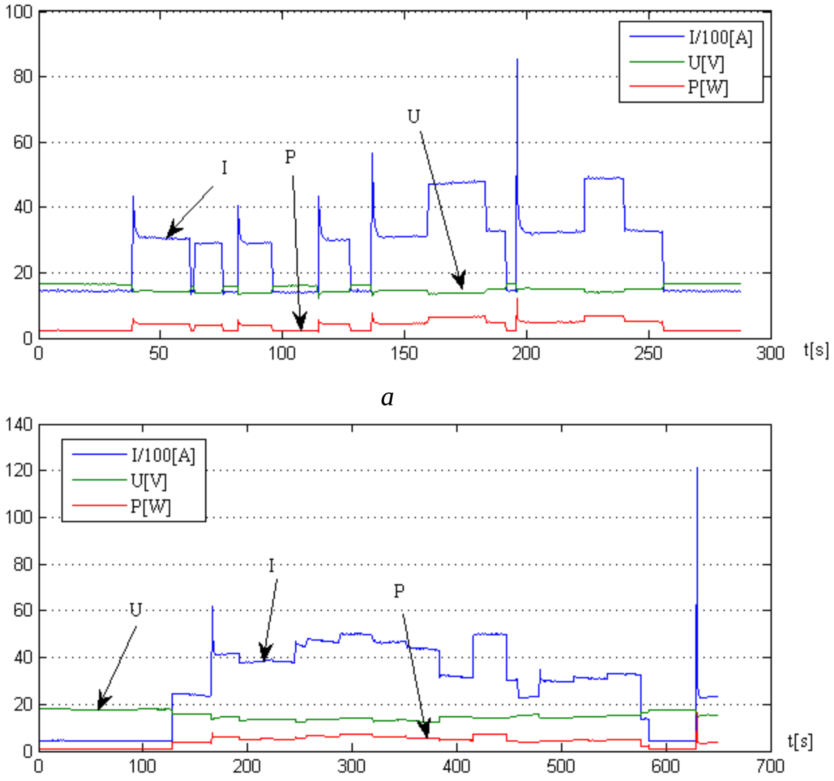


Fig. 3 – Detail of Power supply distribution and control network for power monitoring of a PLC based system.

Fig. 4 shows data measured by the power monitoring module when different loads are switched on and off. The system catches overcurrent states that can activate the alert function. Depending on the configuration of PmodPMON1 module, short overcurrent spikes can be filtered out, the alert being activated only if four consecutive current channel conversions exceed the threshold. Measured data was sent to the PC using the serial port and plotted using Matlab.



a

b

Fig. 4 – Measured data for current, voltage and power when (*a*) two and (*b*) 3 different loads are switched on and off.

The dashboard created for visualization of current, voltage and power of the monitored system includes three panes: the Gauge pane, the Graphics pane and the Alert pane. The Gauge pane includes three gauges for displaying in real time the measured values for current, voltage and power. The Graphics pane includes the spark line type of elements that display graphically the variation of the three measured quantities.

The Alert pane includes three light indicator elements that simulate signaling lamps that can be on or off. These elements are used to display the status of different alerts that can pop in the system. In our example there is an alert for indicating the occurrence of an overcurrent, one for signaling overvoltage and one for notifying low power events.

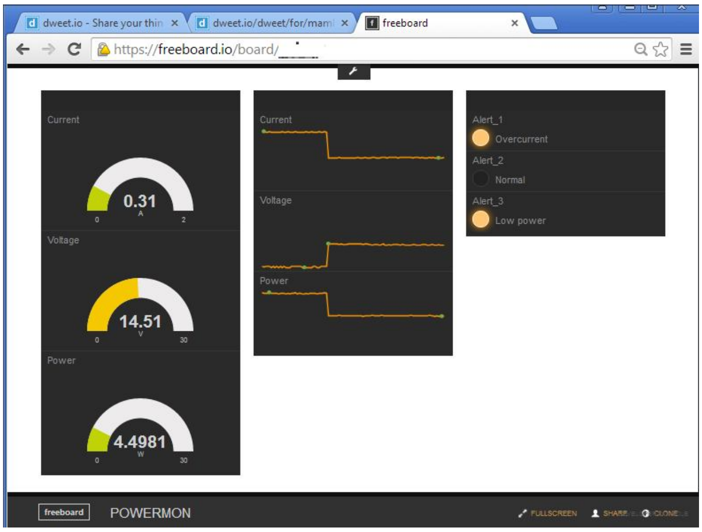


Fig. 5 – Power monitor dashboard created in Freeboard platform monitoring PLC.

The second system that was monitored with the MS is based on an FPGA and includes a dual processor system. For the implementation of the system it was used a Spartan 3E Starter Kit (Spartan-3E Starter Kit…, 2006) which is based on a Spartan X3S500E device. The system includes two Microblaze processors, each one with its different set of peripherals. Each microsystem include general purpose input and output (GPIO) modules connected to pushbuttons, switches or LEDs available on the FPGA board, serial communication modules (UART) and have access to the onboard SRAM memory. The two microprocessors can communicate data or can be synchronized using a set of common peripherals consisting in our case of a mailbox and a mutex. The hardware platform was designed using Xilinx Embedded Design Kit (EDK) version 11.0, while the software running on the two processors was developed and debugged using Xilinx Software Design Kit (SDK) version 11.0.

Fig. 6 depicts the details of the monitored system based on the dual processor system implemented using an FPGA board. Similar to the PLC system, the MS system monitors voltage, current and power consumed by the the FPGA based system and has the possibility to disconnect external input or output circuitry. The monitoring system can be used to measure power consumption of subsystems of the monitored system in order to study different power saving strategies.

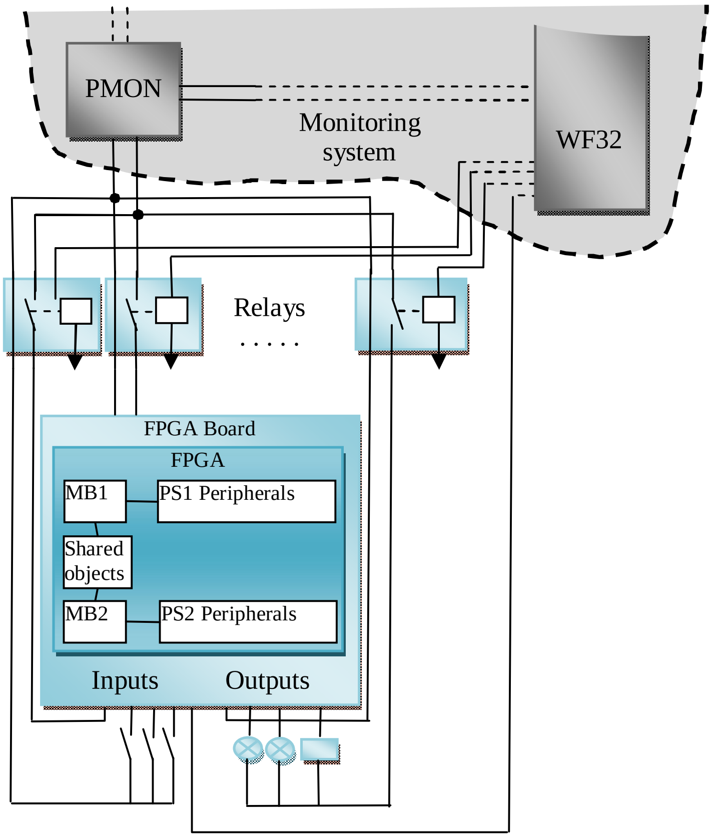


Fig. 6 – Detail of the dual processor FPGA based monitored system.

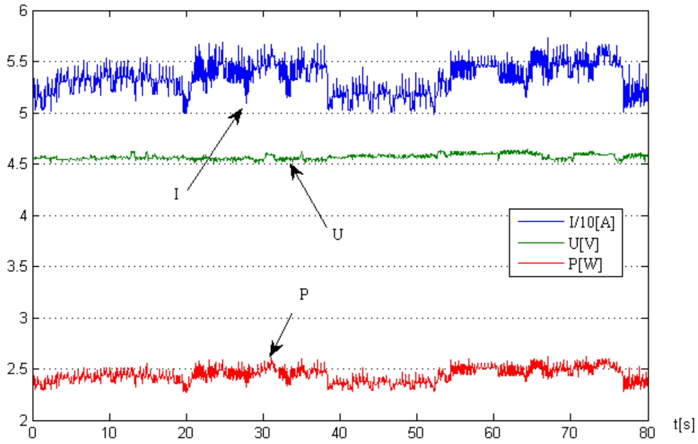


Fig. 7 – Measured data for current, voltage and power for a two processor embedded system.

In Fig. 7 are given the plots of current, voltage and power of the system when the subsystems are in different operation states (stopped or running) or perform different tasks (reading from memory, communicating via the serial port or turning on and off LEDs on the FPGA board.

In order to visualize the numeric values and the plots of the measured quantities, the same dashboard that was used for the PLC based system is employed (Fig. 8).

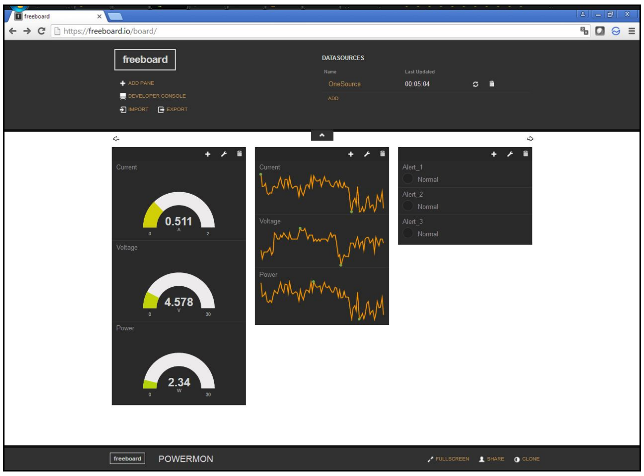


Fig. 8 – Power monitor dashboard created in Freeboard platform monitoring dual processor system.

5. Conclusions

In this paper we have presented an embedded system that can be used for power monitoring of different systems in order to improve energy efficiency of their operation. The proposed system is build around a microcontroller based system and a set of modules for power monitoring, sensing, communication and data display.

The microsystem can connect directly to different systems using a Bluetooth connection or over the Internet using a Wi-Fi connection. Data measured by the system can be exchanged with other systems, stored or processed remotely using cloud service applications.

We want that a future version of the system to communicate more consistently with the PLC or the FPGA based system in order to correlate monitored system operation with measured values for power consumption.

Part of research from this article was presented at the International Conference on Electromechanical and Power Systems, SIELMEN 2015, a joint event organized by the Faculty of Power Engineering - Technical University of

Moldova, Faculty of Electrical Engineering - "Gheorghe Asachi" Technical University of Iasi and Faculty of Electrical Engineering - University of Craiova.

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SISTEM PENTRU MONITORIZAREA ENERGIEI BAZAT PE CIRCUITUL ADM1191

(Rezumat)

Problema eficienței energetice prin reducerea consumului de energie este un subiect fierbinte şi de interes nu numai pentru proiectanții de sisteme noi, ci şi pentru ingineri care doresc să îmbunătățească randamentul sistemelor existente. Lucrarea de față prezintă un sistem care poate fi utilizat pentru a monitoriza consumul de energie şi care conectat prin rețeaua Internet la servicii dedicate de tip "cloud" permite vizualizarea în timp real a mărimilor monitorizate. Sistemul a fost testată în două variante, una dotată cu automat programabil şi una dotată cu circuit programabil de tip FPGA. Sistemul de monitorizare poate deconecta părți ale sistemului monitorizat pentru a identifica componentele consumatoare de energie sau pentru a studia funcționarea sistemului în diferite moduri ce vizează economisirea de energie.