Computer Applications in Electrical Engineering
Vol. 13 *2015*

Remote current measurement with FPGA digital processing

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The work presents an implementation of a modular measurement and control system that controls variants of mains supply of 230V electrical equipment. The system allows to supervise power consumption in the office electronic equipment. The system detects the instant of the reduced power consumption by a device and makes possible its switch-off in order to reduce energy cost. The current is measured with integrated current/voltage converters. The customized hardware has been built for the distributed acquisition system that includes: the data sending module with wireless transmission using ZigBee standard between the measurement point and monitoring point and switching devices. The measurement module was implemented using Altera FPGA.

KEYWORDS: mains supply control, current measurement, FPGA, ZigBee standard

1. Introduction

Industry and public sector utilize large numbers of computer workstations that operate within the infrastructure of an institution. Usually reduction of energy consumed by an individual station is endeavored. Often energy consumption is one of main expenditures, especially in the case of office applications. Therefore various ways of energy consumption are searched for. However, it can be remarked that the obvious approach to reduce the energy consumption is the use of low-power workstations but it is not always applicable. Therefore other approaches are sought for. The simplest are automatic hibernation or complete switch-off instead of going over into stand-by state. The most advanced solutions use dedicated systems that control energy consumption and variants of mains supply [1, 2].

The majority of contemporary computers are designed in compliance with the Energy Star norm [3]. The leading computer manufacturers try to achieve compatibility with the Energy Star norm 5.2 that imposes rigorous requirements pertaining to energy savings. This norm provides the TEC (Typical Energy Consumption) algorithm for estimation of energy consumption for one computer stand. The algorithm allows to compute the yearly energy consumption in the stand-by, switch-off, hibernate and working modes using the energy consumption in the individual modes and their share in the overall working time. Regarding this, the computer equipment has been divided into four classes in dependence upon the energy consumption. For example, using the TEC algorithm we receive for the desktop class from 148 kWh to 234 kWh and for notebooks from 40 kWh to 88 kWh.

It can be observed that in many institutions the computer equipment works round-the-clock. In such a case the energy consumption can be estimated using the data supplied by computer equipment manufacturers. We have measured the energy consumption of typical desktops and it ranges per hour from 0.06 kWh in stand-by mode and to 0.3 kWh for the maximum load, in dependence upon the configuration and computation tasks. Thus for the single computer station that works incessantly seven days a week round-the-clock for one year, with the typical energy consumption of 0.2 kWh, the total yearly energy consumption would be about 1752 kWh. It is seen that the real-life values are remarkably higher, than those resulting from the TEC algorithm.

In this paper we present the design of the current consumption and control measurement system that can be used to reduce energy consumption for devices with 230 V mains supply. In Section 2 the principles of the system operation are described and in Section 3 the processing and execution units are presented.

2. Overview of current consumption and control measurement system

The block scheme of the system for measuring the current consumption is shown in Fig. 1. It consists of three units: measurement unit (MU), control ubnit (CU) and execution unit (EU). The MU includes the integrated current/voltage converters ACS712 [4], processing module and ZigBee transmitter. The converters permit for current measurement in 0 – 5 A range while preserving the linear characteristic. It has been assumed that a single ASC712 measures the current consumed by the single computer stand that can be equipped with a printer, scanner and several LCD monitors. This configuration can be encountered especially in companies that deal with the graphic design or software development.

The processing unit is built using the dedicated System-on-Chip (SoC) in Altera Cyclone V FPGA with Nios II [5] as the main processing unit. The interface devices are used to communicate with peripherals such as 12-bit A/D converter and ZigBee radio transmitter working in 2.4 GHz band. The measured value is processed by the SoC and the information on energy consumption is wirelessly transmitted to the control module.

The control unit in the prototype version was implemented using miniature computer RaspberryPI of the ARM class that maintains the ZigBee radio communication with the measurement and execution modules. The RaspberryPI can be driven from the external 5 V supply source and in the prototype version PoE splitter TP-Link TL-POE10R [6] was used.

The execution unit (EU) uses ZigBee radio transmitter that in this case acts as a controller of relays that switch on or off the supply. The Xbee devices from Digi International working in compliance with IEEE 802.15.4 [7], dispose over up to 10 digital inputs/outputs. This permits to implement a simple controller without using the external microcontroller.

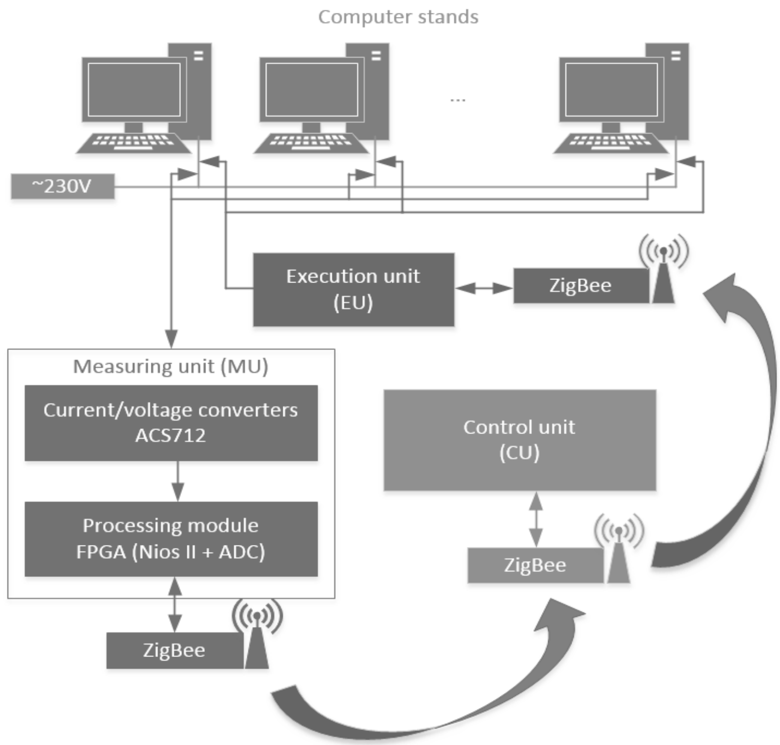

Fig. 1. The block scheme of the unit that controls the variants of supply

The CU that receives the real-time information about instant power consumption in individual stations, is the supervising module. Using the given threshold, the CU detects the instant of the lower current consumption and sends to the EU the command to switch off the given device. This control scenario has been extended in the prototype version by the automatic supply recovery after the fixed period of time. Moreover, the possibility of the manual supply recovery has been also considered. The inclusion of the communication module of the near filed communication (NFC) would provide the possibility of the secure supply switch-on from the application that disposes over some kind of an electronic key. It will allow for access control only for trusted persons.

In Fig. 2 the block scheme of operation of measuring unit is shown. In the first step the current is measured, and its value is transformed to voltage by ACS712 converter and subsequently to the digital form by the A/D converter. Finally exceeding of the threshold is detected, and the information is transmitted to the CU.

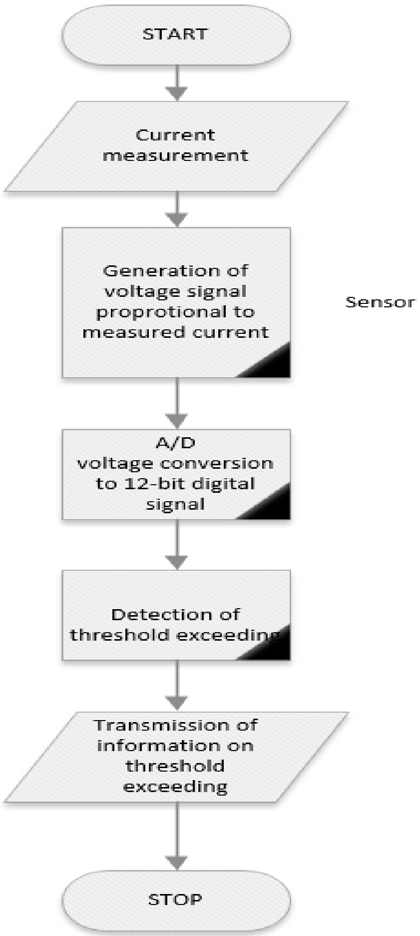

Fig. 2. The algorithm of the measurement unit operation

In Fig. 3 the algorithm of the control unit is presented. First, identification of the measurement point is performed, the diagnostic message is received. Next follows the readout of states of energy consumption and storing in the table of states. If the state of current consumption is greater than critical the readout is continued else the output states of the given stand is recorded and the information about the need to switch off the mains supply is sent to the execution unit.

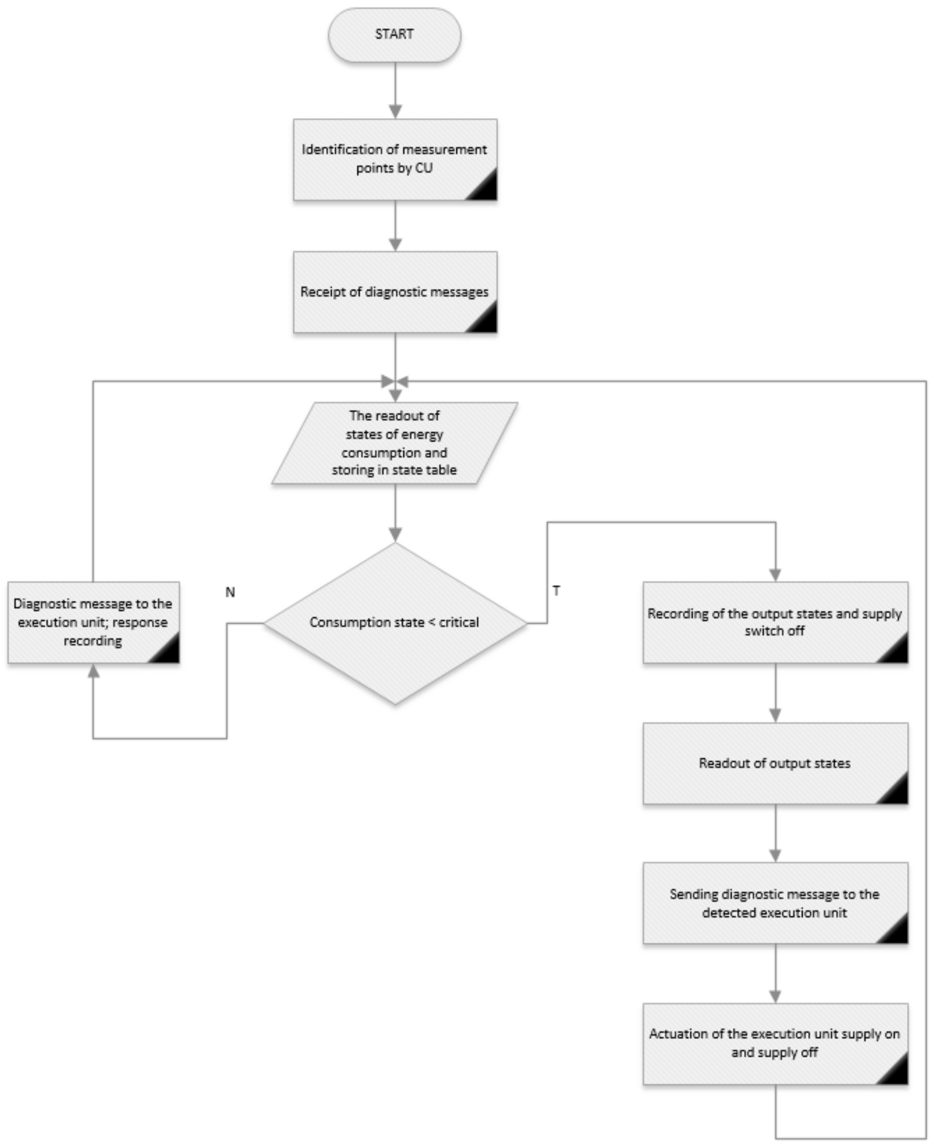

Fig. 3. The algorithm of control unit operation

In Fig. 4 the algorithm of the execution unit operation is depicted. The EU receives and decodes the message and in dependence upon the content of the message the appropriate is taken. The message may convey only the diagnostic information or a command to switch off the given stand. In the latter case the corresponding relay is activated and the mains supply is switched off.

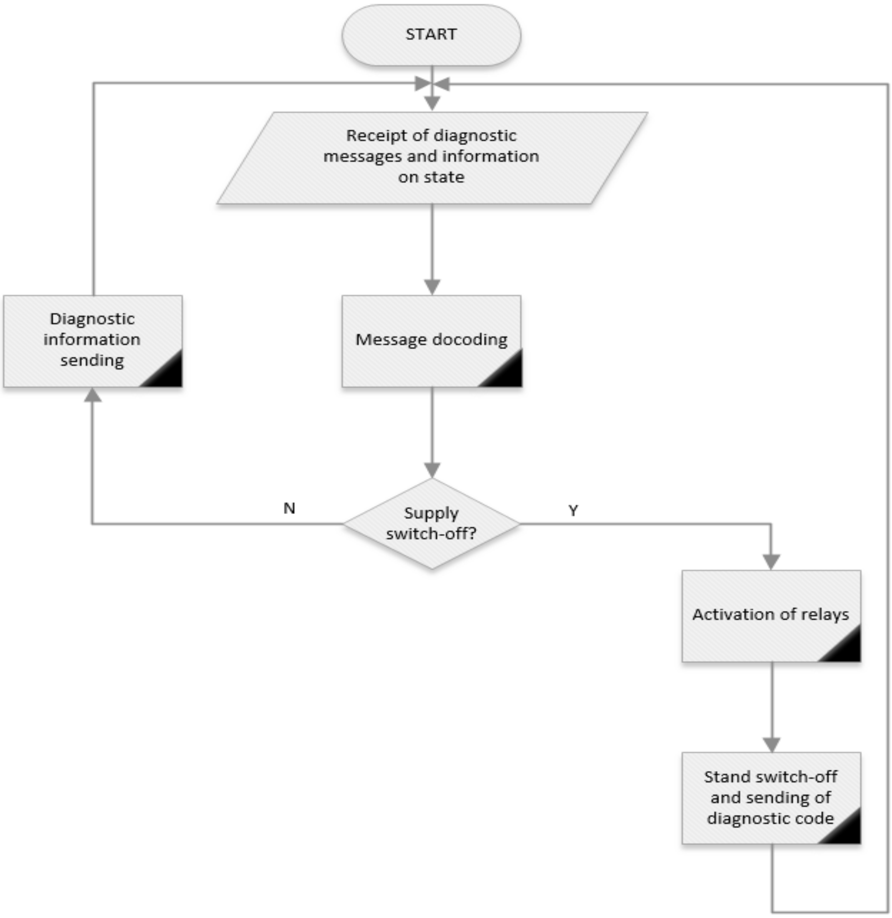

Fig. 4. The algorithm of the execution unit operation

3. Implementation of the processing unit

The measurement unit is the main processing module that implements the processing of information about the current measured at the given computer station. As shown in Figure 5 the programmed controller is based on Nios II (**nios2_qsys_0**). This processor provides the flexibility of configuration of the hardware components as well as the software control of the controller module. This module has integrated memory (**onchip_memory2_0**), communication modules UART and SPI (**jtag_uart_0** i **de0_nano_adc_0**). The SoC design has been elaborated in the Quartus II environment and hardware was implemented with the use of TerasIC DE0 Nano [8] board. In Figure 6 an exemplary C code for data readout from the A/D converter is given.

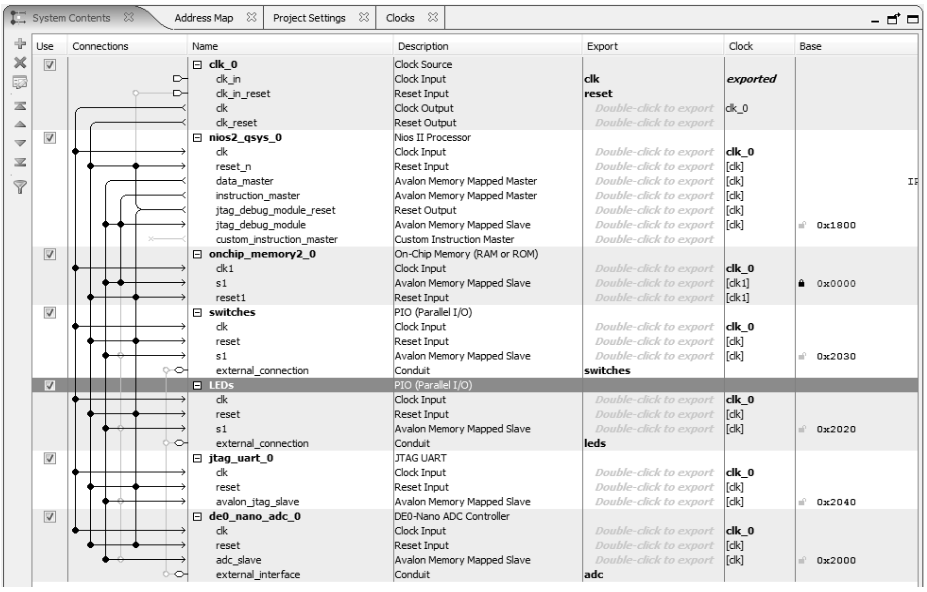

Fig. 5. The scheme of internal connections of the processing module in SoC

```
#define ADC_ADDR 0x00009000
#define LED_ADDR 0x00009040
#define UART_ADDR 0x00009020
//RXD - C3 gpio0p1
//TXD - D3 gpio0p0
void putchar(volatile int * uart, char c);
void puts(volatile int * uart, char *c);
void kasuj_lancuch(char *c, int n);
void dec2str(char *c, int n);
int strlen(char *c);
int main (void){
        volatile int * adc = (int*)(0x00009000);
        volatile int * sw = (int*)(0x00009050);
        volatile int * led = (int*)(0x00009040);
        volatile int * uart = (int*)(0x00009020);
        unsigned int data;
        int count;
        int channel;
        char pomiar[20];
        data = 0;
        count = 0;
        channel = 0;
        while (1){
                *(adc) = 0; //Start the ADC read
                count += 1;
                data = *(adc+channel); //Get the value of the selected channel
                data = data/16; //Ignore the lowest 4 bits
                *(led) = data; //Signalize the ADC value on the LEDs
                if (count==500000){
                        count = 0;
                        channel = !channel;
                        //Sending measured value to UART
                        puts(uart,"CH");
                        kasuj_lancuch(pomiar,20);
                        dec2str(pomiar,data);
                        puts(uart,pomiar);
                        puts(uart,"$\0");//Comment it for Xbee comunication

                }
        }
        return 0;
}
```

Fig. 6. The listing of the exemplary code to read data from the A/D converter using Nios II

4. Results of experimental measurements

In order to properly select the current/voltage converter, the experimental measurements of power and current consumption for several computer stations during the start of the operating system and during the normal work with the office software have been carried out. The obtained data was presented in Table 1. It has been stated that the current consumption for the desktop PC is in the range of 600 mA to 900 mA when viewing a document within a word processor and reading the spreadsheet. For notebooks with the rich configuration typically 300 mA are needed and for the standard laptops 140 mA.

Table 1. The measurements of power and current consumption for computer stands during the selected variants of operation

Computer stand configuration	System state	Power	Current
PC desktop (typical), Intel Core Quad, HDD 250GB, RAM 4GB, monitor 19"	Switched-off	4 W	61 mA
	System start	about 160 W	900mA – 1100 mA
	Office work	max 160 W	max 900mA
PC notebook (typical) Intel Core i3, HDD 500GB, RAM 3GB	Switched-off	0,5 W	About 20 mA
	System start	max 35 W	Max 180 mA
	Office work	20 W	Max 140 mA
PC notebook (rich configured) Intel Core i7, HDD 500GB, RAM 16GB	Switched-off	0,5 W	About 20 mA
	System start	Max 75 W	300 mA
	Office work	Max 60 W	Max 300 mA
PC desktop (rich configured) Intel Core i7, 2 x HDD 1TB, RAM 32GB	Switched-off	2 W	<30 mA
	System start	About 160 W	900 mA
	Office work	128 W	537 mA

The application of ACS712 converters allows to measure current in the range of 0 – 5 A with precision of 180 mV/A. In practice it allows to control the variants of supply of up to five desktops.

5. Conclusions

In this work an implementation of the system for the remote measurement of current consumed by computer stations during the system start, normal operation and stand-by mode has been presented. The modular system has been implemented that consists of measurement units, control unit and communication using the ZigBee standard devices. The system uses the software processor Altera Nios II implemented within the Cyclone V FPGA. The current measurement is performed using ACS712 converters. It has been stated that the system that controls the energy consumption may be beneficial for installations with a huge number of computer stations. Morover, it can be useful when there is a need to completely cut off the supply of computer stands without switching off the supply of the floor or building.

The system consists of a certain number of programmable units that can be optionally assembled in various configurations. This allows to easily adapt the unit to a concrete, often very specific, work environment. The more important functional requirements encompass: monitoring of current consumption in 230 V installation, the distributed installation of modules of the unit, adaptation of the adequate number of unit parameters by changing its control software and the use of components with a very small energy consumption. The total cost for power management system can be estimated as in Table 2.

Table 2. Estimation of hardware cost for power management system with 20 workstations

Name	Qty.	Unit price [PLN]	Total cost [PLN]
ACS712 sensor	20	20	400
Xbee	7	120	840
Main control module (FPGA)	1	1 000	1000
Embedded server (www, database)	1	1 000	1000
Software development	1	5 000	5000
Additional equipment	1	800	800
Total			**9040**

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(Received: 20. 10. 2015, revised: 1. 12. 2015)