Monitoring system for AC current up to 20A

Milan Savić, Dejan Stevanović and Miona Andrejević Stošović, *Member, IEEE*

***Abstract*—This paper presents a system for AC current monitoring in home appliances up to 20A. It is implemented on a custom made PCB. System also measures voltage, line frequency, power factor, active power and total imported active energy. Measurement results can be obtained by a remote computer or some other device via serial RS-485 interface. Consumer is enabled to have bigger control over real-time current consumption by installing several monitoring devices and connecting them into a network.**

***Index Terms*—Energy efficiency, Modbus RTU, monitoring system.**

I. Introduction

Energy efficiency has a fundamental role to play in the transition towards a more competitive, secure and sustainable energy system. Although energy powers our societies and economies, future growth must be driven with less energy and lower costs. According to the Energy Efficiency Communication of July 2014 [1], the EU is expected to achieve energy savings of 18%-19% by 2020. Reduced power consumption leads to reduced emissions and, consequently, reduced carbon footprint. This is a straightforward benefit. However, this could happen only if EU countries implement all of the existing legislation on energy efficiency. Unfortunately, efficiency of electrical distribution is currently not much managed or planned by utilities. The unfavourable result is that most utilities waste considerable amounts of electricity. For example, the annual value of transmission and distribution losses runs up to 6% of total generated energy [2]. These losses mainly occur in the low and medium voltage lines, and also in primary and secondary substations. One way for reducing losses and increasing efficiency on low level power distribution system is improving the system for registration of electric energy consumption [3-4]. Another way is to implement home energy monitoring system. A lot of similar systems have been already developed [5]. Some of realized systems are described in [6-8].

Economic return is one of the major reasons why households should consider and adopt smart energy management products. A home energy monitoring system allows consumers to have significant role in energy management activities. It can be implemented by using smart sockets. Probably, the simplest and most straightforward way to monitor and control energy usage is by replacing traditional sockets and plugs with the smart ones.

Milan Savić is with the College of Applied Technical Sciences Niš, Aleksandra Medvedeva 20, 18000 Niš, Republic of Serbia (e-mail: milan.savic@ vtsnis.edu.rs).

Dejan Stevanović and Miona Andrejević Stošović are with University of Niš, Faculty of Electronic Engineering, Aleksandra Medvedeva 14, Niš, Serbia,{dejan.stevanovic, miona.andrejevic}@elfak.ni.ac.rs.

Namely, placing multiple measurement devices in the household enables that consumer has nearly instant information about current consumption of each appliance. Some smart sockets contain relay, so that turning load on and off is supported. In this paper we proposed a system that can be implemented at electric panel. Moreover, our system can be used as smart fuses.

This paper is organized as follows. In the next section, the basic definitions that correlate power parameters with measured current and voltage data will be given. The third chapter will be dedicated to description of realised system, while in the fourth chapter measurement results will be given. The conclusion is in the fifth section.

II. Definitions of electric power quantity

The core of our system is a MCP39F521 [9] which calculates all power quantities that are of interest for utility to control consumption. Usually, these values are defined by appropriate standards. All these circuits relay on digital signal processing of voltage and current samples. The instantaneous value of voltage and current are attenuated through voltage divider, while for current can be used current transformers, Rogowski coil sensors or shunt resistors. The first set of signal conditioning that occurs inside MCP39F521 is shown in Fig.1.

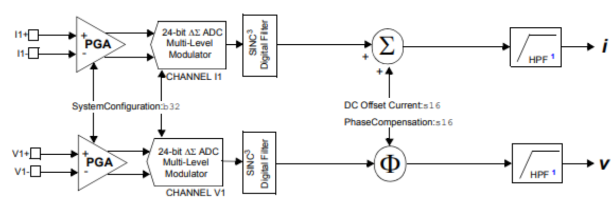


Fig. 1. Channel I1 and V1 signal flow

The obtained signal at output of attenuator is sent to ADC where it is sampled at discrete time points (at least two per period, according to the Nyquist-Shannon theorem) and digitalized. DSP processes digital voltage and current samples and calculates all necessary power quantities. Instantaneous value of signal (current or voltage) in time domain can be expressed as:

$$x(t) = \sqrt{2} X_{RMS} \cdot \cos(2\pi f t + \varphi) \quad (1)$$

After the discretization in equidistant time intervals, it is transformed to:

$$x(nT) = \sqrt{2} X_{RMS} \cdot \cos(2\pi \frac{f}{f_{sempl}} n + \varphi) \quad , \qquad (2)$$

where f and f_{sempl}, are frequency of the signal and the sampling frequency, respectively. The RMS value is calculated using the following equation:

$$X_{RMS} = \sqrt{\frac{\sum_{n=1}^{N} x(nT)^2}{N}} \quad . \qquad (3)$$

The signal flow of calculation of RMS current and voltage values is presented in Fig. 2.

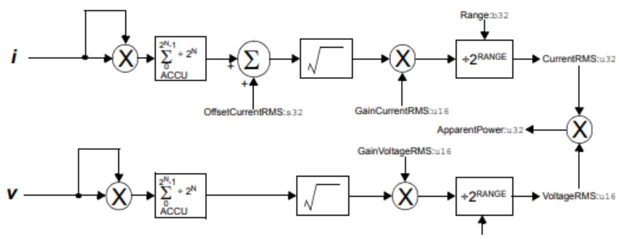


Fig. 2. RMS current and voltage calculation signal flow

The active power is obtained as average value of the multiplied instantaneous values of current and voltage, by using Eq. (4). Signal flow of active power calculation is shown in Fig. 3. The MCP39F521 has two simultaneous sampling A/D converters. For active power calculation, the instantaneous currents and voltages are multiplied in order to create instantaneous power. The instantaneous power is then converted to active power by averaging or calculating DC component.

$$P = \frac{\sum_{n=1}^{N} v(nT) i(nT)}{N} = \frac{\sum_{n=1}^{N} p(nT)}{N} . \qquad (4)$$

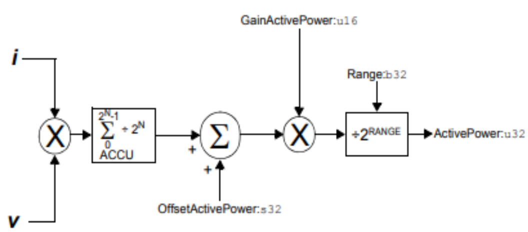


Fig. 3. Active power calculation signal flow

III. REALIZED SYSTEM

The block diagram and photography of our system are shown in Fig. 4. As can be seen from Fig. 4a our system consists relay circuit, RS485 circuit, current/voltage sensor circuit, power measuring circuit and MCU. We used a well-known microcontroller Atmega328P [10] as MCU, which characteristics meet all our demands. MCU communicates with power measuring circuit (MCP39F521) by using I2C protocol and passes the obtained data through RS485 to central monitoring system by using Modbus RTU protocol.

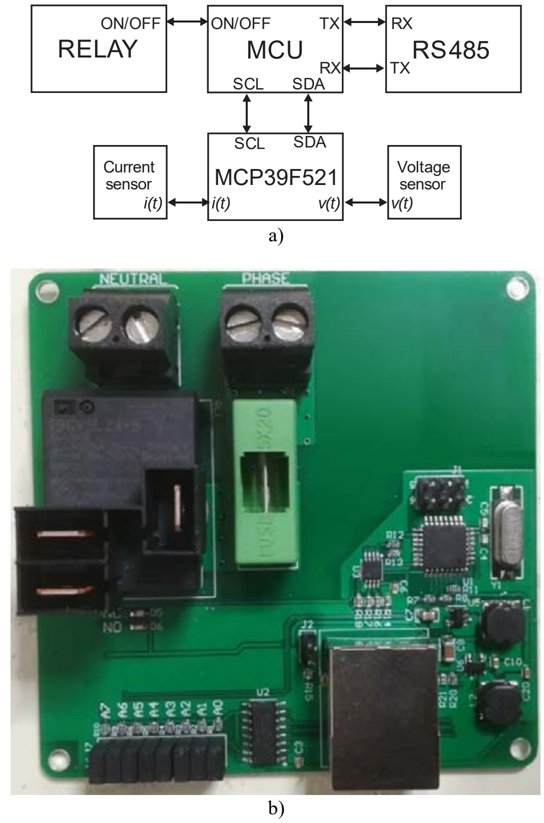


Fig. 4. a) Block diagram of realized system, b) photo of realized system

RS485 interface supports multiple devices on the same bus. This interface is currently widely used in data acquisition and control applications where multiple nodes communicate with each other. Consequently, each board needs to have unique address (unique on the network level). Because of that remote monitoring computer can send request only to specific node in a network. This address can be set by using jumpers in our system. The maximum number of nodes on the same RS-485 network in our case is 213 [11]. The number of supported devices on same networks depends on IC that is used for RS485 interface, bound rate and distance between nodes.

The load is powered via the T9A series relay, which has normal open (NO) and normal closed terminals (NC) [12]. The relay can be set to normal closed state, which is useful in applications where electrical appliance has to be always on, but on demand it can be turned off. Typical example of this usage is refrigerator in hotel rooms which needs to be always powered on. When customer exits the room, all electrical outlets and devices are disabled, except refrigerator which is connected via the relay board.

As we said before, communication between computer and our device is done by using Modbus RTU protocol and QModMaster application. We use only four functions from Modbus RTU:*write single coil, write multiple coil, read input registers and read holding registers.*

The state of relay can be controlled by using *write single coil* or *write multiple coil* function, while reading measurement results is done by using *read input registers* or *read holding registers* functions. These registers contain value of RMS voltage/current, line frequency, power factor, active power and total accumulated energy, as shown in Fig.5.

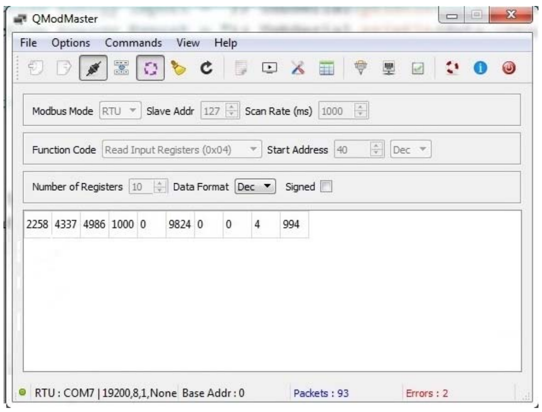


Fig. 5. Modbus application

QModMaster application runs on central computer which is used for reading data from each relay board. For connecting PC to RS-485 network USB-RS485 bridge is used. Before connecting relay board on the network, it is necessary to set slave address of the board, by setting appropriate jumper configuration. In Fig. 5, we showed obtained data when using *read input registers* function. By using this function and setting number of register to 10 we obtain: RMS voltage/current (registers 1 and 2), line frequency (register 3), power factor(register 4), active power(registers 5 and 6) and active energy(registers 7 to 10), respectively. In order to get good accuracy of read values, we introduce correction factors. This factor for voltage is 10, for line frequency and active power is 100, while for current, power factor and active consumed energy is 1000. The negative values of power factor are presented with digit 1 on the 5th position at register 4.

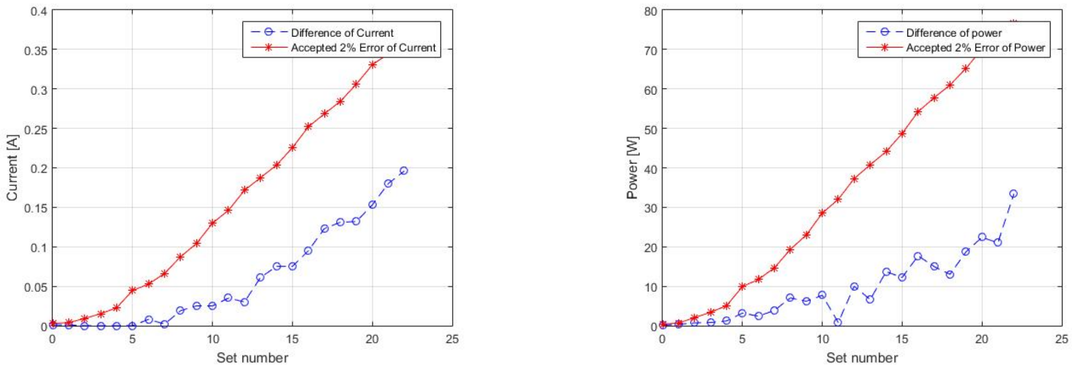
IV. Measurement results

The accuracy of the realized system is verified by using a set of different linear and nonlinear loads. As nonlinear loads we chose LED and CFL bulbs. These nonlinear loads are chosen as benchmarks because they characterize small nominal power. Namely, the intention is to show that our system measures current in range from 0.1A to 20A with accuracy less than 2%, having different load conditions. For linear load measuring we have used industrial resistor whose resistance can be set in range from 16.66 **Ω** to 500 **Ω**, heater and different types of incandescent light bulbs (ILB). As reference measuring instrument, we have used electronic power meter produced by EWG electronics [13]. It fulfils the IEC 62052-22 standard [14], IEC 62052-23standard [15]. The previously mentioned standards, fulfilled by power meter, guaranty to us that power meter has good accuracy.

TABLE I
Measurement results

		Power Meter			**Our System**					
NO.	TYPE OF LOAD	U_{RMS}	I_{RMS}	P (W)	U_{RMS}	I_{RMS}	P (W)	V_{RMS} Error(%)	I_{RMS} Error(%)	P Error(%)
1	CFL20W	225	0.135	17.7	224.8	0.134	17.8	0.09	0.75	0.56
2	LED10W+CFL20W	224.8	0.193	32.72	224.7	0.194	32.4	0.04	0.52	0.99
3	R=500Ω	225	0.455	102	225.00	0.455	102.70	0.00	0.00	0.68
4	R=300Ω	224.7	0.758	169.9	224.70	0.758	170.70	0.00	0.00	0.47
5	R=200Ω	224.6	1.131	253	224.20	1.131	254.20	0.18	0.00	0.47
6	R=100Ω	223.5	2.23	494.6	222.90	2.230	497.80	0.27	0.00	0.64
7	R=500Ω&ILB100W	223.1	2.632	586.2	222.6	2.640	588.6	0.22	0.30	0.41
8	R=70Ω	222.6	3.309	733.33	222.1	3.311	737.2	0.23	0.06	0.52
9	R=50Ω	221.44	4.368	966.37	221.1	4.387	973.4	0.15	0.43	0.72
10	R=50Ω&ILB200W	220.09	5.207	1150.2	220.05	5.232	1156.4	0.02	0.48	0.54
11	R=35Ω	219.8	6.495	1425.6	219.1	6.520	1433.3	0.32	0.38	0.54
12	R=35Ω&ILB200W	218.8	7.311	1600.6	218.2	7.346	1601.4	0.27	0.48	0.05
13	R=25Ω	217.6	8.574	1864	217	8.604	1874	0.28	0.35	0.53
14	R=25Ω&ILB200W	217.44	9.375	2038.9	216.5	9.436	2045.5	0.43	0.65	0.32
15	R=25Ω&ILB400W	216.73	10.171	2206	215.8	10.246	2219.7	0.43	0.73	0.62
16	R=25Ω&ILB650	216.03	11.272	2435.5	215	11.347	2447.7	0.48	0.66	0.50
17	R=16.66Ω	215.38	12.6	2711	214.3	12.695	2728.7	0.50	0.75	0.65
18	R=16.66Ω&ILB200W	214.7	13.424	2888	213.9	13.547	2903	0.37	0.91	0.52
19	R=16.66Ω&ILB400W	214.51	14.215	3050	213.1	14.346	3063	0.66	0.91	0.42

20	R=16.66Ω&ILB650W	212.85	15.3	3260	211.8	15.432	3278.7	0.50	0.86	0.57
21	R=16.66Ω&Heater&ILB200W	212.56	16.533	3506	210.9	16.686	3528.4	0.79	0.92	0.63
22	R=16.66Ω&Heater&ILB400W	211.4	17.22	3641	209.3	17.400	3662	1.00	1.03	0.57
23	R=16.66Ω&Heater&ILB650W	210.7	18.25	3833	209.1	18.446	3866.4	0.77	1.06	0.86



a) b)

Fig. 6. a)Accuracy of current for load shown in Table I , b) Accuracy of power for load shown in Table I

As it is shown in Table I and Fig 6.,after measurements with all the loads, we obtained accuracy less than 2%.

V. Conclusion

This paper presented a current and power monitoring system with accuracy less than 2%. Measuring of voltage, current, line frequency and active power for household appliances gives us sufficient information on which we can perform some action. Built-in relay with NO and NC contacts drastically increases practical usability of our system, so that remote controlling of appliance is also supported. This is very important in terms of creating a power scheme, so that some device can be powered only during night hours, or in case of some unpredicted behaviour we can switch off corresponding device, etc. In the future our goal will be to expand monitoring capabilities so that reactive and apparent power can be measured. Also, beside RS-485 interface, adding WiFi and/or Bluetooth capability will affect places where physically adding cables for RS-485 interface is not an option.

Acknowledgment

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