SINGLE-LOAD POWER MONITORING SYSTEM

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Abstract: In this paper we proposed a system for AC current monitoring in home appliances, up to 20A. System also measures voltage, line frequency, power factor, active power and total imported active energy. The accuracy of the realized system is examined by using a set of different linear and nonlinear loads. In order to get better accuracy, less than 1%, calibration is performed.

Keywords: Energy efficiency, Modbus RTU, monitoring system.

INTRODUCTION

An energy monitoring system in a household allows consumers to have significant role in energy management activities. This is crucial for the development of a smarter, more flexible and more eco-friendly energy system. Moreover it ensures that investment in the grid is implemented as effectively and optimally as possible for the benefit of society as a whole. It can be implemented by using smart sockets or smart meters. Probably, the simplest and most straightforward way to monitor and control energy usage is by replacing traditional sockets and plugs with the smart ones.

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.

Another option to have significant role in energy management activities and also in reducing emission of CO_2 is using smart meter with available HAN port. Namely, all new power meters installed in Norwegian homes are fitted with an output terminal called a HAN port (Home Area Network) [1]. You can connect to the HAN port by yourself, but you need to contact your utility company in order to open your HAN port. Data retrieved from your HAN port belongs to you. This means that if a utility company or any other third party wants to retrieve data from your HAN port, it has to enter into an agreement with you. Also, Norway plans to introduce new tariff structures in 2021, which will probably entail higher prices at peak load periods. In response to this, you can save money on your electricity bill by moving your consumption to periods when the load on the grid is lower. We believe that our device can give customer more accurate information about which load consumes more power at specific time and which consuming we should move for period when electricity is cheaper.

SYSTEM REALIZATION

A block diagram of our system is shown in Fig. 1. As can be seen from the Figure, it contains relay circuit, RS485 circuit, current and voltage sensor circuit, power measuring circuit (MCP39F521) [2], and MCU. We used a well-known microcontroller Atmega328P [3] as MCU, which characteristics meet all our demands. MCU communicates with power measuring circuit by using I2C protocol and passes the obtained data through RS485 to central monitoring system by using Modbus RTU protocol.
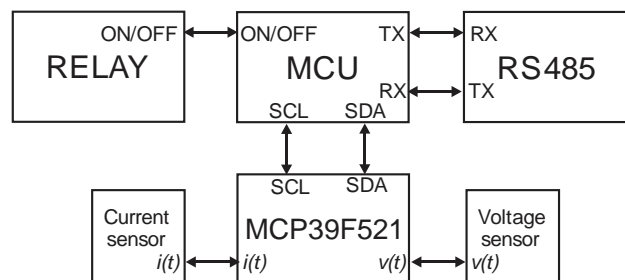

Fig. 1 – *Block diagram of realized system*

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 RS485 network in our case is 213 [4]. The number of supported devices on the same network 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) [5]. The relay can be set to normal closed state, which is useful

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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. 2 QModMaster application runs on central computer which is used for reading data from each relay board. For connecting PC to RS485 network, a 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. 2, we showed obtained data when using *read input registers* function. By using this function and setting number of register to 10 we obtain: RMS volt-

age/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. Some similar solutions can be found in [6-9].
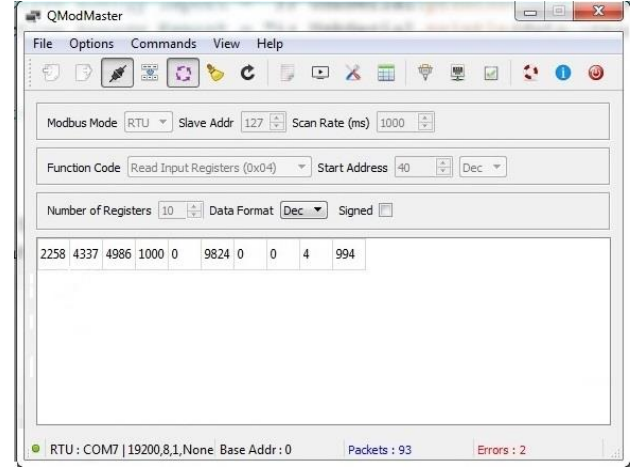

Fig. 2 - *Modbus application*

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Table I

Measurement results

NO.	TYPE OF LOAD	Power Meter			Our System					
		U_{RMS}	I_{RMS}	P (W)	U_{RMS}	I_{RMS}	P (W)	V_{RMS} Error(%)	I_{RMS} Error(%)	P Error(%)
1	LED10W	229.3	0.056	11.8	228.8	0.051	11.4	9.80	3.51	3.51
2	CFL20W	229.3	0.138	19.08	229	0.138	19	0.00	0.42	0.42
3	LED10W+CFL20W	229.2	0.172	30.23	228.7	0.175	30.6	1.71	1.21	1.21
4	ILB100W	229	0.436	99.72	228.70	0.427	98.10	2.11	1.65	1.65
5	ILB250W	228.5	1.175	268.2	227.80	1.150	263.4	2.17	1.82	1.82
6	ILB450W	227.5	2.043	465	227.00	2.000	457.3	2.15	1.68	1.68
7	ILB650W	226.7	2.912	660	226.20	2.860	649.0	1.82	1.69	1.69
8	HR (HEATER)	226.3	3.545	802.4	225.7	3.481	787	1.84	1.96	1.96
9	HR+ILB100W	226.1	3.972	897	225.3	3.905	883	1.72	1.59	1.59
10	HR +ILB250W	225.6	4.704	1061	224.7	4.622	1041	1.77	1.92	1.92
11	HR+ILB450W	225.2	5.55	1250	224.2	5.456	1226	1.72	1.96	1.96
12	HR +ILB650W	224.3	6.404	1437	223.4	6.295	1408	1.73	2.06	2.06
13	WATER KETTLE (WK)	222.6	8.067	1793	221.4	7.918	1760	1.88	1.88	1.88
14	WK+LED10W+CFL20W	222.5	8.231	1825	221.4	8.074	1793	1.94	1.78	1.78
15	HR+WK	220.2	11.385	2499	218.7	11.186	2450	1.78	2.00	2.00
16	HR+WK+ILB100W	220	11.759	2585	218.3	11.573	2535	1.61	1.97	1.97
17	HR+WK +ILB250W	219.4	12.461	2734	217.8	12.260	2676	1.64	2.17	2.17
18	HR+WK +ILB450W	218.6	13.255	2900	217	13.065	2845	1.45	1.93	1.93
19	HR+WK +ILB650W	218.3	14.077	3074	216.6	13.856	3098	1.59	0.77	0.77

MEASUREMENT RESULTS

The accuracy of the realized system is verified by using a set of different linear and nonlinear loads. For 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 1%, having different load conditions. For linear load measuring we have used water kettle and different types of incandescent light bulbs (ILB). As reference measuring instrument, we have used electronic power meter produced by EWG electronics [10]. It fulfils the IEC 62052-22 standard [11], IEC 62052-23standard [12]. The previously mentioned standards, fulfilled by power meter, guaranty to us that power meter has good accuracy. Table I presents obtained results after measurements. As we can see the obtained accuracy (for P and I_{RMS}) is around 2%. This accuracy is according to MCP39F521 specification. Namely, manufacturers of MCP39F521 claim that by choosing low-tolerance resistors at input of current and voltage channels (e.g. 1% tolerance), measurement accuracy in the 2-3% range can be achieved with zero calibration. As we said before our goal is to design system with accuracy less than 1%. To achieve that, we need to do calibration of MCP39F521, which is shown in the next section.

CALIBRATION PROCEDURE

When performing calibration, one compensates ADC gain error, component tolerances and overall noise in the system. The device provides an on-chip calibration algorithm that allows simple system calibration to be performed quickly. The excellent analog performance of the A/D converters on the MCP39F521 allows for a single point calibration and a single calibration command to achieve accurate measurements.

Calibration can be done either by using the predefined auto-calibration commands, or by writing directly to the calibration registers. In our case we decided to directly write gain value into calibration register. In order to achieve that, we have to use some reference measuring unit. We will include reading from this unit into calculation. The new value of gain will be sent to relay board by using QmodeMaster application. Currently we can change only current and active power gain register at relay board. To achieve that, in QmodeMaster application we set function code to WriteMultipleRegisters (0x10) and set new value for current and active power gain.
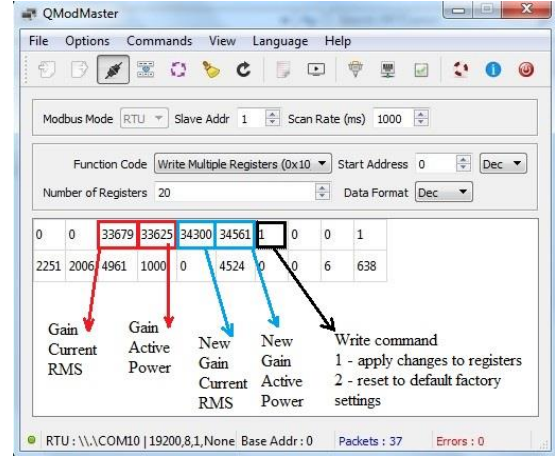

Fig. 3 - *Modbus calibration*

New gain value is obtained by using equation:

$$Gain_{NEW} = Gain_{OLD} * \frac{Expected}{Measured} \qquad (1)$$

Value that is calculated by this equation needs to be between 25000 and 65535.

For example, if our referent measuring device is showing current of 2043 mA (expected value) and relay board is showing 2006 mA (measured value, showed as 2006 in the corresponding field), we need to adjust current gain register.
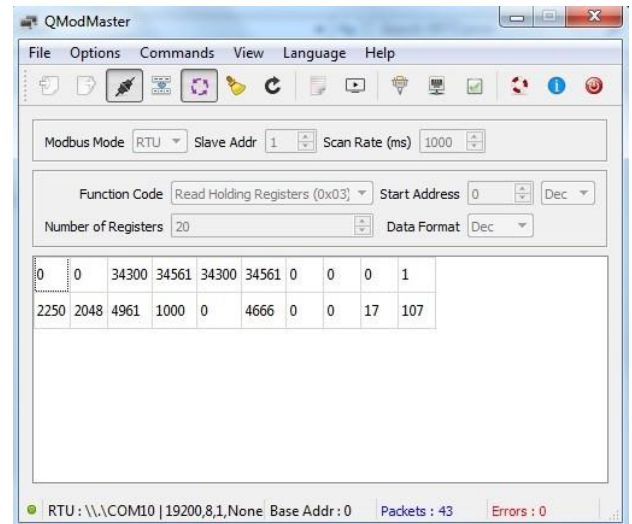

Fig. 4 – *Measurements parameters after calibration*

Table II
Measurements results after calibration

NO.	TYPE OF LOAD	Power Meter			Our System			V_{RMS} Error (%)	I_{RMS} Error (%)	P Error (%)
		U_{RMS}	I_{RMS}	P (W)	U_{RMS}	I_{RMS}	P (W)			
1	LED10W	228.16	0.056	11.95	228	0.053	12	0.07	5.66	0.42
2	CFL20W	228	0.136	19	227.5	0.135	19.1	0.22	0.74	0.52
3	LED10W+CFL20W	228	0.184	31.6	227.8	0.184	31.9	0.09	0.00	0.94
4	ILB100W	227.8	0.442	100.7	227.50	0.441	101.70	0.13	0.23	0.98
5	ILB250W	227.19	1.176	267.6	226.80	1.176	270.20	0.17	0.00	0.96
6	ILB450W	226.26	2.049	463.8	225.60	2.048	468.20	0.29	0.05	0.94
7	ILB650W	225.57	2.911	656.66	225.00	2.911	663.00	0.25	0.00	0.96
8	HR (HEATER)	224.86	3.57	797.4	224.3	3.600	804	0.25	0.83	0.82
9	HR+ILB100W	224.7	3.964	889	224.1	3.967	897	0.27	0.08	0.89
10	HR +ILB250W	224.01	4.667	1050	223.5	4.683	1060	0.23	0.34	0.94
11	HR+ILB450W	223.6	5.54	1250	222.8	5.529	1262	0.36	0.20	0.95
12	HR +ILB650W	222.6	6.364	1415	221.8	6.363	1428	0.36	0.02	0.91
13	WATER KETTLE (WK)	221.2	8.043	1772	220.3	8.000	1783	0.41	0.54	0.62
14	WK+LED10W+CFL20W	221.19	8.16	1805	220.1	8.165	1823	0.50	0.06	0.99
15	HR+WK	218.7	11.279	2466	217.5	11.300	2468	0.55	0.19	0.08
16	HR+WK+ILB100W	218.3	11.764	2552	217	11.723	2576	0.60	0.35	0.93
17	HR+WK +ILB250W	218	12.369	2695	216.6	12.384	2709	0.65	0.12	0.52
18	HR+WK +ILB450W	217.2	13.163	2860	215.8	13.194	2881	0.65	0.23	0.73
19	HR+WK +ILB650W	216.7	13.96	3023	215.4	13.990	3045	0.60	0.21	0.72

In Fig. 3. we see that current gain is 33679 (factory calibrated value). Including all this into above equation we get that new gain is 34300. The results presented in the Table II demonstrated that we successfully implemented calibration procedure and we obtained system which can measure active power in wide range with accuracy less than 1%.

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. In order to obtain accuracy less than 1%, we additionaly performed calibration of the system. Measuring of the system performance after calibration confirmed that calibration process was properly done.

Monitoring capabilities of the system can be further improved by capturing values of reactive and apparent power. Also, by adding WiFi and/or Bluetooth capability we can reach places where physically adding cables for RS485 interface is not an option. These are goals to be achieved in the next period.

REFERENCES

[1] " Data from HAN ports fitted to smart meters (AMS) can provide you with valuable information - #SINTEFblog
[2] https://ww1.microchip.com/downloads/en/DeviceDoc/20005442A.pdf
[3] https://ww1.microchip.com/downloads/en/DeviceDoc/ATmega48A-PA-88A-PA-168A-PA-328-P-DS-DS40002061B.pdf
[4] https://www.ti.com/lit/ds/symlink/sn65hvd72.pdf?HQS=dis-dk-null-digikeymode-dsf-pf-null-wwe&ts=1621931109406
[5] https://www.te.com/commerce/DocumentDelivery/DDEController?Action=srchrtrv&DocNm=1308242_T9A&DocType=DS&DocLang=English
[6] https://nerdtechy.com/best-smart-home-energy-monitor
[7] J. G. Josué, J. M. Pina, M. V. Neves "Home Electric Energy Monitoring System: Design and Prototyping", Proceedings of Technological Innovation for Sustainability – Second IFIP WG 5.5/SOCOLNET Doctoral Conference on Computing 2011, Costa de Caparica, Portugal, 21 – 23. February, 2011, pp. 437 - 444.
[8] E. Barakat, N. Sinno, C. Keyrouz,"*A Remote Monitoring System for Voltage,, Current, Power and Temperature Measurements*", vol 55, no.1, pp. 421 – 428, 2014.
[9] M. J. Manti,A. V Bossche, R. F. Chisab "A Smart Voltage and Current Monitoring System for Three Phase Inverters Using an Android Smartphone Application", Sensors 2017, DOI:10.3390/s17040872
[10] EWG - multi metering solutions, www.ewg.rs
[11] IEC 62053-22 Electricity metering equipment (AC) - Particular requirements - Static meters for active energy (classes 0.2S and 0.5S).
[12] IEC62053-23 (2003) Electricity metering equipment (a.c.) – Particular requirements – Part 23: Static meters for reactive energy (classes 2 and 3)