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MONITORING OF AC MOTOR SPEED CONTROLLER PARAMETERS IN AN IoT NETWORK

GOCE STEFANOV, VASILIJA SARAC

Abstract. Today's development of electronics mainly takes place in two directions. One direction is based on the technological development of semiconductor elements that will work in a larger current, voltage and frequency range. The other direction is based on the development of information bases and systems that will ensure the collection, visualization, processing and transport of process parameters. The first direction will enable applications in power electronics for higher powers and process speeds, and the second local and remote transmission of process data and their availability in intranet and internet networks. Taking this into account in the paper, an electronic system is designed and implemented that measures, stores and transmits the parameters of a 1-phase AC motor speed controller in an IoT network. The solution enables the visualization of input and output parameters locally on two LCD displays and remotely on an IoT device. A data log file is also provided for the measured values on a local computer and on an IoT cloud platform.

1. Introduction

The power electronics contributes to the fast and reliable design of power converters designed to regulate the speed of both DC and AC motors [1]. The development of the power electronics is based on the development of power switch integrated circuit [2].

In the last few years in the design of power converters mainly power MOS and IGBT transistors have been used. Power MOS transistors provided applications for frequencies up to 500 kHz, currents up to 100 A, and voltages up to 200 V. Power IGBT transistors have been used in applications for voltages up to 1800 V, currents up to 600 A and frequencies up to 100 kHz. Both types of power transistors were based on a silicon semiconductor element. The efforts of microelectronics were directed to the design of power switches with higher current-voltage characteristics and higher switching frequency. The results showed that the use of silicon carbide and gallium nitrate as a semiconductor element provides the possibility of designing energy switches for higher voltages, currents and switching frequency. So, today there are power switches that operate at frequencies up to 500 kHz, currents up to 5000 A and voltages up to 10,000 V.

On the other hand, there are mainly two directions of development of integrated circuits that are used in the power electronics. On one side are microcomputers [3], [4] and on the other side are typical integrated circuits designed for special purposes [5], [6]. Microcomputers are intelligent electronic components that have a number of advantages over discrete electronic components. Their main advantage is the increased packaging density of the chip itself. This is the result of the application of new technologies in the development of microelectronics, which allows over a million

Keywords: AC motor controller, Integrated circuit, Data log file, Blynk cloud

discrete electronic elements to be integrated into an area of 1 cm^2. Their second advantage, which distinguishes them from discrete electronic components, is their flexibility of application. The latter implies the ability to run different applications with the same network hardware, and with software changes. But, on the other hand, the design of electronic circuits with a microcomputer requires knowledge of appropriate software and in the development of the product converter it is necessary to include more specialists who know the hardware, software and related knowledge to the topologists of the converters.

Unlike from the design of the converters based on a microcomputer, the design based on a special circuit requires reduced knowledge of hardware and software, and only a good knowledge of converter topology is enough to make a successful converter product [5], [6]. Clearly, which approach will be chosen in the design of the converter depends on its nominal power. But, for small and medium power up to 5kW, it can be said that the design of a converter with special circuits is more economically justified.

For the design of the solution, the paper takes into account that automation, control, management, and monitoring processes are of exceptional importance, especially for industrial use [7]. Efforts are made to ensure more reliable and simpler work, especially for operators who are directly exposed to the proper functioning of the entire industrial process. This approach implies the use of LCD panels and monitors for the visualization of measured values as well as programs for their storage in a data log file [8], [9].

Even more, it should be taken into account that a modern controlled system of an industrial process is fully rounded if it is also connected to an IoT network, [10]. Such a concept enables process data to be transferred to any location, visualized in real-time, and stored in the cloud.

Commonly, some standalone industrial processes might represent a separate entity. Since these plants are far from the Intra and Internet network of manufacturing companies, the data distribution of analog and digital signals from sensors and actuators of some process quantities (voltage, current, pressure, flow, temperature, LEDs, relay, etc.) must be made from these remote entities to the master station via wireless communication, most likely a radio frequency (RF) connection [11].

There are various wireless communication technologies used in building IoT applications and RF is one of them. Usually, such radio communications are two-way or bidirectional [12], [13], [14].

Bearing in mind what has been said above in this paper, an electronic system is designed and implemented that measures, stores and transmits the parameters of a 1-phase AC motor speed controller in an IoT network.

2. Design and Monitoring of AC Motor Speed Controller Parameters in an IoT Network

The design of the electronic system subject of this paper includes the design of an AC motor speed controller and the design of the system for measurement, monitoring and transfer of the controller parameters. The block diagram of this electronic system is shown in Figure 1.

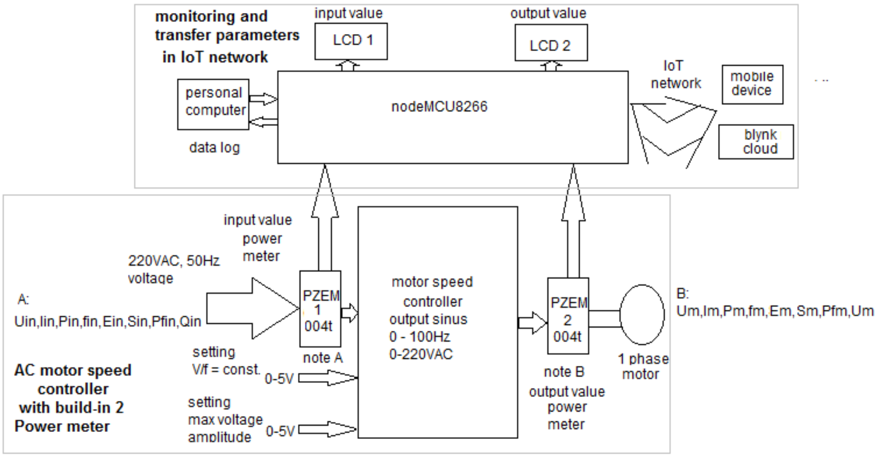


Figure 1. *Design monitoring AC motor speed controller parameters to IoT network.*

2.1 Design of AC Motor Speed Controller

In Figure 1 the AC motor speed controller consists of: input voltage 220 VAC, 50 Hz, smart power meter PZEM1 004t and motor controller, smart power meter PZEM2 004t and 1-phase motor, [15]. PZEM1 power meter measurement input parameters: voltage *U*in, current *I*in, active power *P*in, active energy *E*in, frequency *f*in, appearance power *S*in, power factor *P*fin and reactive power *Q*in. PZEM2 power meter measurement input parameters: voltage *U*m, current *I*m, active power *P*m, active energy *E*m, frequency *f*m, appearance power *S*m, power factor *P*fm and reactive power *Q*m.

The design of the AC motor speed controller is based on a special integrated circuit EG 8010 embedded on board EG002, [5], [6].

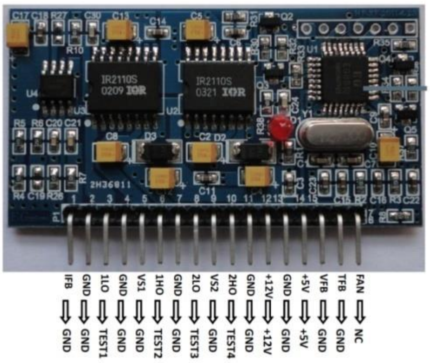
a.) EG 8010 Special Integrated Circuit

EG 8010 can ensure that the source (converter) operates in mode on variable output voltage and constant frequency, in mode on constant voltage and variable frequency and in mode on variable voltage and variable frequency. The first and second mode are used for AC voltage consumers and the third for AC motor speed regulation. In our case, it is used in the mode on variable voltage and variable frequency, i.e., as an AC motor speed controller.

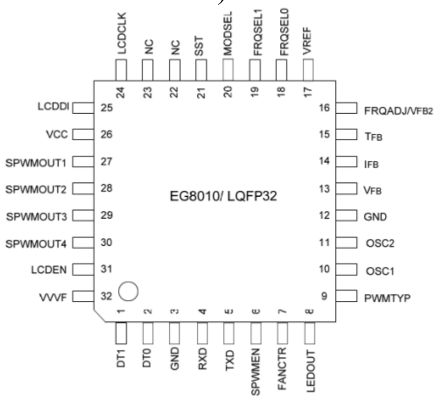
In this paper, a converter design based on EG 8010 in mode on variable voltage and variable frequency is made. EG8010 has two frequency modes: constant frequency mode and adjustable frequency mode. In adjustable frequency mode, EG8010 only uses unipolar modulation, and pin (20) MODSEL has to connect to low level. Pins FRQSEL1 and FRQSEL0 set the frequency mode.

- In constant frequency mode, 50Hz (FRQSEL1, FRQSEL0 = 00) or 60 Hz (FRQSEL1, FRQSEL0 = 01), Pins FRQADJ/VFB2 and VVVF have no effect. AC output voltage is adjusted by the feedback resistor R23. This application can be used in as a dimmer and voltage regulator.
- In variable frequency and constant voltage mode (Pin VVVF at “0” low electrical level) 0～100 Hz (FRQSEL1, FRQSEL0 = 10) or 0 Hz～400 Hz (FRQSEL1, FRQSEL 0= 11), pin FRQADJ needs to connect an external adjustable resistor. Pin FRQADJ adjusts output frequency and R23 sets output voltage.
- In variable frequency and variable voltage mode (Pin VVVF at “1” high electrical level) 0～100 Hz (FRQSEL1, FRQSEL0 = 10) or 0 Hz～400 Hz (FRQSEL1, FRQSEL0 = 11), pin FRQADJ needs to connect an external adjustable resistor. Pin FRQADJ sets output frequency and voltage. EG8010 maintains V/F as a constant. R23 sets output frequency at 50Hz when voltage effective value is 220V.

  Figure 2 shows the physical appearance of the electronic board EG002 where IC EG8010 and driver IRF2110 and its pinout are embedded.



a.)



b.)

Figure 2. *a.) Electronic board EGS002 with build IC EG8010 and driver IRF2110, b) his pinout*

Figure 3 shows an electrical connected circuit when EG8010 operates as a variable frequency and variable voltage controller.

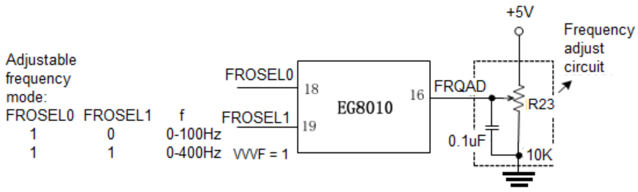


Figure 3. *Electrical connected circuit where EG8010 operates as a variable frequency and variable voltage controller.*

b.) Power meter PZEM-004T

The power meter is mainly used for measuring AC voltage, current, active power, frequency, power factor, apparent energy, active energy, reactive power, and reactive energy. The module is without a display function while the data could be read through the TTL interface. PZEM-004T-10A built-in shunt has a measuring range of 10A, and PZEM-004T-100A with external transformer has a measuring range of 100A, [15]. Figure 4 represents the board of the PZEM-004T power meter.

Figure 4. *The board on the PZEM-004T power meter*

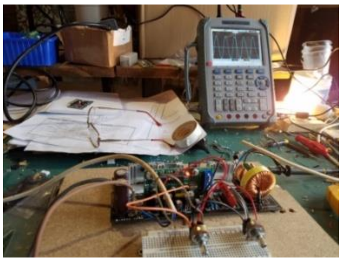
The current signal is connected to the power meter on the terminals NIN and NOUT, and the voltage is connected to the terminals LIN and LOUT. The power meter is supplied with 5 VDC voltage. The terminals TX and RX are for serial communication.

2.1.1 Experimental Results of Prototype AC Motor Speed Controller

The operation of the EG8010 circuit is experimentally illustrated in the mode of variable voltage and variable frequency. For this purpose, the corresponding pins of the EG 8010 are set as follows: for source with 100 Hz variable frequency pins FRQSEL1, FRQSEL0 = 10, or for source with 400 Hz variable frequency pins FRQSEL1, FRQSEL0 = 11, and pin VVVF is set in logical 1. An adjustment resistor connected in pin FRQADJ sets the output frequency and the voltage.

A prototype of a voltage/frequency AC motor speed controller is designed and practically realized. The designed AC motor controller prototype is tested when it is loaded with a 1-phase motor, (a three-phase motor is used, which is adapted to work on one phase with a capacitor. The motor is for nominal voltage 3x220V, 50 Hz, current 2.2A, power 0.45kW).

Figure 5a shows the prototype in the testing phase and Figure 5b shows the output voltage and current waveforms of the AC motor controller when the output frequency is 21 Hz. In Figure 5b, the blue waveform shows the output current and the yellow waveform shows the output voltage. In the same figure it can be seen that the waveforms are sinusoidal. The vertical base for the voltage waveform is 100 V/div, and the vertical base for the current waveform is 200 mV/div.



a.) b)

Figure 5. *Prototype of practically realized voltage/frequency sine source: a.) in the manufacturing phase, b.) the output voltage and current waveforms of the AC motor controller when the output frequency is 21 Hz, horizontal div is 40 ms.*

It should be noted that the current is measured by a 50/5 current transformer placed at the output terminals of the AC controller. A 1 Ω resistor is placed on the secondary of the current transformer, so the oscilloscope shows an effective voltage value of 312 mV which corresponds to a real output current of 3.12 ((312mV /1Ω)x10 = 3.12 A. Also, from Figure 5 it can be seen that the effective value output voltage is 108 V and the maximum voltage amplitude is 180 V.

2.2 Design of System for Measurement, Monitoring and Transfer of AC Motor Speed Controller Parameters

This part of the designed system accepts the signals from the power meters PZEM1 and PZEM2 and, after appropriate software processing with NodeMCU 8266, it visualizes them on the two LCD displays and sends them to the IoT network, [10]. Figure 6 shows a connected diagram of circuit for measurement, transfer and sending of AC motor controller parameters.

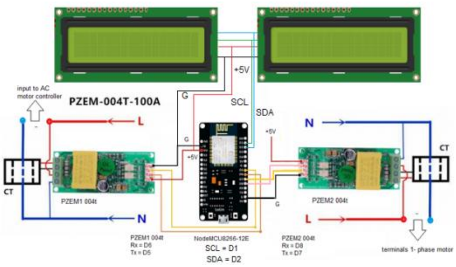
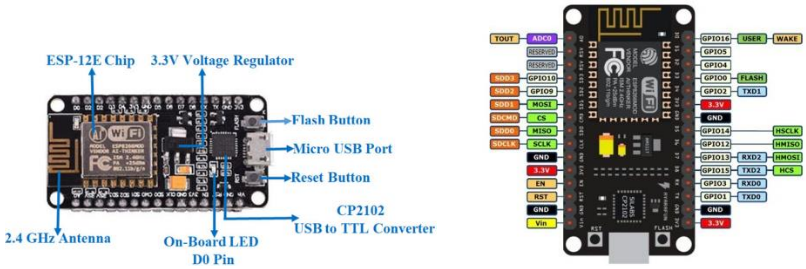


Figure 6. *Connected diagram on circuit for measurement, transfer and sending of AC motor controller parameters*

a.) ***Microcomputer NodeMCU ESP8266***

The NodeMCU ESP8266 development board comes with the ESP-12E module containing the ESP8266 chip having the Tensilica Xtensa 32-bit LX106 RISC microprocessor. This microprocessor supports RTOS and operates from 80MHz to 160 MHz adjustable clock frequency. NodeMCU has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power with built-in Wi-Fi / Bluetooth and Deep Sleep Operating features makes it ideal for IoT projects. NodeMCU can be powered using Micro USB jack and VIN pin (External Supply Pin). It supports UART, SPI, and I2C interface. Figure 7 showsn NodeMCU ESP8266 and its pinout.



a.) b.)

Figure 7. a.) *NodeMCU ESP8266 and b.) its pinout*

NodeMCU is an open-source based firmware and development board specially targeted for IoT based applications. It includes firmware that runs on the ESP8266 Wi-Fi SoC from Espressif Systems, and hardware which is based on the ESP-12 module. In Table 1 the pinout of this microcomputer is given.

Table 1**:** NodeMCU Development Board Pinout Configuration

Pin Category	**Name**	**Description**
Power	Micro-USB, 3.3V, GND, Vin	**Micro-USB:** NodeMCU can be powered through the USB port **3.3V:** Regulated 3.3V can be supplied to this pin to power the board **GND:** Ground pins **Vin:** External Power Supply
Control Pins	**EN, RST**	The pin and the button reset the microcontroller
Analog Pin	A0	Used to measure analog voltage in the range of 0-3.3V
GPIO Pins	GPIO1 to GPIO16	NodeMCU has 16 general purpose

		input-output pins on its board
SPI Pins	SD1, CMD, SD0, CLK	NodeMCU has four pins available for SPI communication.
UART Pins	TXD0, RXD0, TXD2, RXD2	NodeMCU has two UART interfaces, UART0 (RXD0 & TXD0) and UART1 (RXD1 & TXD1). UART1 is used to upload the firmware/program.
I2C Pins		NodeMCU has I2C functionality support but due to the internal functionality of these pins, you have to find which pin is I2C.

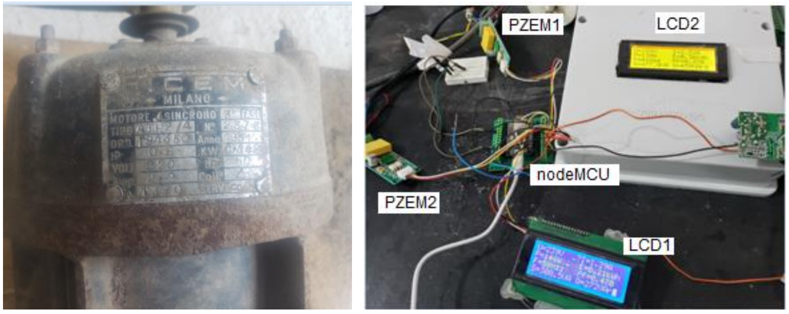
NodeMCU ESP8266 Specifications & Features

- Microcontroller: Tensilica 32-bit RISC CPU Xtensa LX106
- Operating Voltage: 3.3V
- Input Voltage: 7-12V
- Digital I/O Pins (DIO): 16
- Analog Input Pins (ADC): 1
- One UARTs port
- One SPIs port
- One I2Cs port
- Flash Memory: 4 MB
- SRAM: 64 KB
- Clock Speed: 80 MHz
- USB-TTL based on CP2102 is included onboard, Enabling Plug and Play
- PCB Antenna
- Small Sized module to fit smartly inside your IoT projects

The NodeMCU ESP8266 board can be easily programmed with Arduino IDE since it is easy to use.

3. Experimental Results of Testing the Designed System

This section presents the results of the experimental work on the prototype system for measuring, monitoring and transporting the parameters of the AC motor speed controller. At the output of the controller the same motor as in the design of the AC motor controller is connected, i.e., a 1-phase motor, (a three-phase motor is used, which is adapted to work on one phase with a capacitor). The motor is for nominal voltage 3x220V, 50 Hz, current 2.2A, power 0.45kW. Figure 8a shows the used motor with the table of its nominal parameters, and Figure 8b shows the test prototype of the designed system.



a.) b.)

Figure 8. *a.) used motor with the table of its nominal parameters and b.) test prototype of the designed system*

The designed system is tested when the AC motor is running at idle with no load and when it is coupled mechanically with another motor as a load. Figure 9 shows the used AC motor coupled mechanically with another motor.

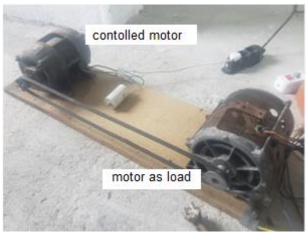
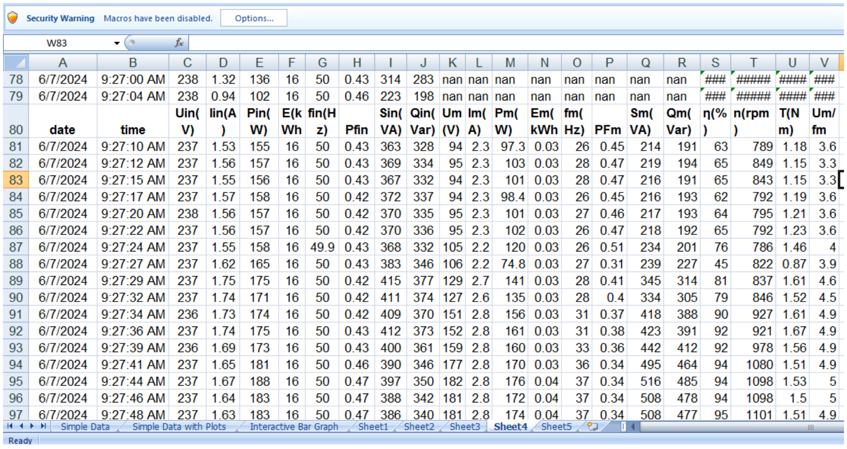


Figure 9. *Used AC motor coupled mechanically with another motor*

Figure 10 shows a print screen of a data log file in Excel for monitoring the input and output parameters of the AC motor controller obtained with the designed system in the paper.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	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
78	6/7/2024	9:27:00 AM	238	1.32	136	16	50	0.43	314	283	nan	nan	nan	nan	nan	nan	nan	nan	###	#####	####	###
79	6/7/2024	9:27:04 AM	238	0.94	102	16	50	0.46	223	198	nan	nan	nan	nan	nan	nan	nan	nan	###	#####	####	###
80	date	time	Uin(V)	Iin(A)	Pin(W)	E(kWh	fin(Hz)	Pfin	Sin(VA)	Qin(Var)	Um(V)	Im(A)	Pm(W)	Em(kWh	fm(Hz)	PFm	Sm(VA)	Qm(Var)	η(%)	n(rpm)	T(Nm)	Um/fm
81	6/7/2024	9:27:10 AM	237	1.53	155	16	50	0.43	363	328	94	2.3	97.3	0.03	26	0.45	214	191	63	789	1.18	3.6
82	6/7/2024	9:27:12 AM	237	1.56	157	16	50	0.43	369	334	95	2.3	103	0.03	28	0.47	219	194	65	849	1.15	3.3
83	6/7/2024	9:27:15 AM	237	1.55	156	16	50	0.43	367	332	94	2.3	101	0.03	28	0.47	216	191	65	843	1.15	3.3
84	6/7/2024	9:27:17 AM	237	1.57	158	16	50	0.42	372	337	94	2.3	98.4	0.03	26	0.45	216	193	62	792	1.19	3.6
85	6/7/2024	9:27:20 AM	238	1.56	157	16	50	0.42	370	335	95	2.3	101	0.03	27	0.46	217	193	64	795	1.21	3.6
86	6/7/2024	9:27:22 AM	237	1.56	157	16	50	0.42	370	336	95	2.3	102	0.03	26	0.47	218	192	65	792	1.23	3.6
87	6/7/2024	9:27:24 AM	237	1.55	158	16	49.9	0.43	368	332	105	2.2	120	0.03	26	0.51	234	201	76	786	1.46	4
88	6/7/2024	9:27:27 AM	237	1.62	165	16	50	0.43	383	346	106	2.2	74.8	0.03	27	0.31	239	227	45	822	0.87	3.9
89	6/7/2024	9:27:29 AM	237	1.75	175	16	50	0.42	415	377	129	2.7	141	0.03	28	0.41	345	314	81	837	1.61	4.6
90	6/7/2024	9:27:32 AM	237	1.74	171	16	50	0.42	411	374	127	2.6	135	0.03	28	0.4	334	305	79	846	1.52	4.5
91	6/7/2024	9:27:34 AM	236	1.73	174	16	50	0.42	409	370	151	2.8	156	0.03	31	0.37	418	388	90	927	1.61	4.9
92	6/7/2024	9:27:36 AM	237	1.74	175	16	50	0.43	412	373	152	2.8	161	0.03	31	0.38	423	391	92	921	1.67	4.9
93	6/7/2024	9:27:39 AM	236	1.69	173	16	50	0.43	400	361	159	2.8	160	0.03	33	0.36	442	412	92	978	1.56	4.9
94	6/7/2024	9:27:41 AM	237	1.65	181	16	50	0.46	390	346	177	2.8	170	0.03	36	0.34	495	464	94	1080	1.51	4.9
95	6/7/2024	9:27:44 AM	237	1.67	188	16	50	0.47	397	350	182	2.8	176	0.04	37	0.34	516	485	94	1098	1.53	5
96	6/7/2024	9:27:46 AM	237	1.64	183	16	50	0.47	388	342	181	2.8	172	0.04	37	0.34	508	478	94	1098	1.5	5
97	6/7/2024	9:27:48 AM	237	1.63	183	16	50	0.47	386	340	181	2.8	174	0.04	37	0.34	508	477	95	1101	1.51	4.9

Simple Data | Simple Data with Plots | Interactive Bar Graph | Sheet1 | Sheet2 | Sheet3 | Sheet4 | Sheet5

Ready

Figure 10. *Print screen of a data log file in Excel for monitoring the input and output parameters of the AC motor controller*

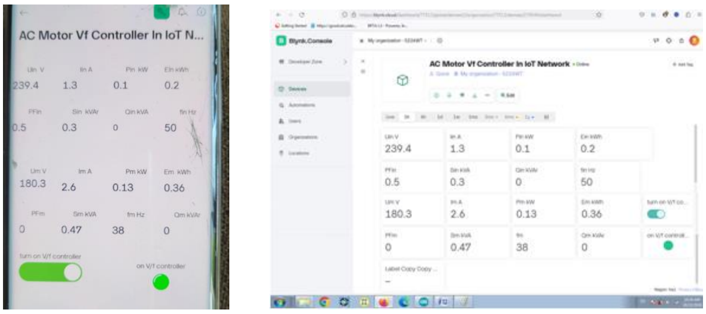
For the sake of clarity, the input and output parameters are given in Figure 10 only for controller output frequencies up to 37Hz. Table 2 provides data of the input and output parameters for several measuring points.

Table 2: Data of input and output parameters for several measuring points

Uin V	Iin A	Pin W	Ein Wh	fin Hz	Pf	Sin VA	Qin VAr	Um V	Im A	Pm W	Em Wh	fm Hz	Pfm	Sm VA	Qm VAr	η %	n rpm
237	1.5	155	16	50	0.4	363	328	94	2.3	97	0	26	0.5	214	191	63	789
236	1.73	174	16	50	0.4	409	370	151	2.78	156	0	30.9	0.37	418.2	388.1	90	927
237	1.65	181	16	50	0.5	390	346	177	2.8	170	0	36	0.34	494.6	464.3	94	1080
237	1.66	191	16	50	0.5	393	343	190	2.74	176	0	40.3	0.34	520.8	490.2	92	1209
237	1.49	180	16	50	0.5	352	303	220	2.39	167	0	46	0.32	525.7	498.5	93	1380
237	1.12	133	16	50	0.5	265	229	219	1.56	125	0	50.8	0.37	341	317.3	94	1524
237	1.03	125	16	50	0.5	244	209	216	0.75	118	0	60	0.73	162.7	111.8	94	1800
237	1.15	140	16	50	0.5	272	233	214	0.64	131	0	65.1	0.96	136.9	39.56	93	1953
237	1.5	184	16	50	0.5	356	305	212	0.97	170	0	72.2	0.83	204.8	113.7	93	2166
236	2.05	255	16	50	0.5	484	411	209	1.52	236	0	79.3	0.74	317.6	213.1	92	2379
236	2.41	318	16	50	0.6	568	470	206	1.96	291	0	84	0.72	404.1	281	91	2520

Figure 11 shows a monitoring data screen on a mobile device in which the AC motor controller parameters are transferred in the IoT network, and Figure 11b represents a screen of the IoT Blynk cloud network [16].

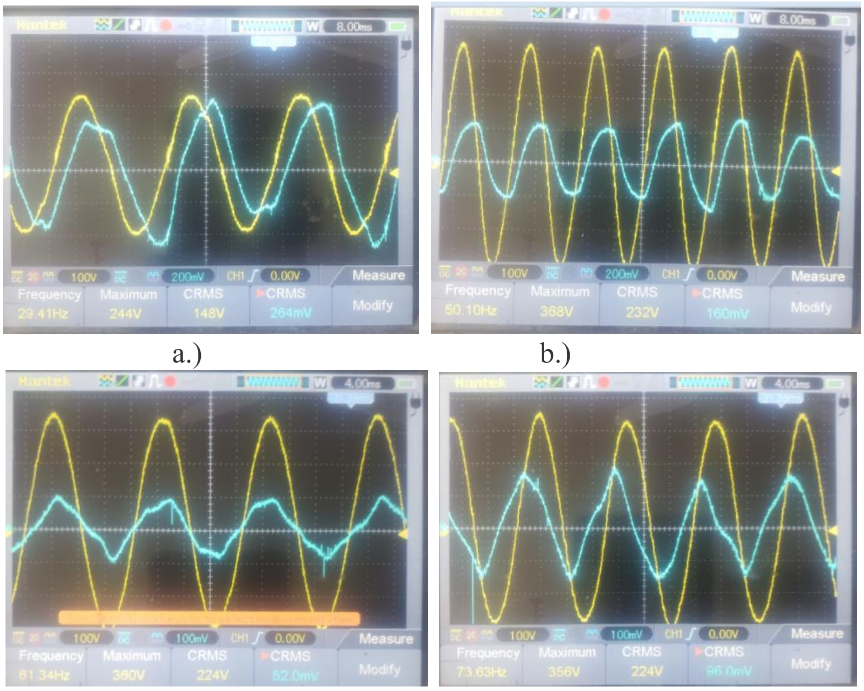
Figure 11 shows that, in addition to the values of the input and output parameters, there are also blocks for a switch and a LED. With the switch from the IoT network, the AC motor controller can be turned on, and the LED indicates the state of the controller, i.e., whether it is turned on or off.



a) b)

Figure 11. *Monitoring AC motor controller parameters: a) screen of mobile device, b.) screen of IoT Blynk cloud network*

Figure 12 shows a waveform of the output voltage and current for several operating frequencies of the controller.



a.) b.)

c.) d)

Figure 12. *Waveform of the output voltage and current for several operating frequencies of the controller: a.) fm = 29.41 Hz, Um = 148 V, Im = 2.84 A; b.) fm = 50.1 Hz, Um = 232 V, Im = 1.6 A; c.) fm = 61.34 Hz, Um = 224 V, Im = 0.62 A; d.) fm = 73.63 Hz, Um = 224 V, Im = 0.96 A*

3.1 Analysis of the results

The main task of the paper is to design and implement a prototype test system for measuring, monitoring and transferring of an AC motor speed controller parameters in an IoT network. The analysis of what is presented above in the paper shows that:

- In point 2.1, the prototype circuit of the AC motor controller was designed and the results of its operation were verified in point 2.1.1;
- The results show that the AC motor controller regulates the motor speed;
- In point 2.2, a prototype of the system for measurement, monitoring and transfer of the parameters of the AC motor speed controller was designed and implemented;
- Section 3 gives the results of the experimental work of the solution in the paper;
- The results show that the system measures, visualizes on LCD screens and stores in a data log file the parameters of the AC motor controller and sends them to a cloud platform and a mobile IoT device;
- The print screen shown in Figure 10 is provided to verify that the solution in the paper stores the data in a data log file in Excel. The data in Table 2 is extracted to this data log file;
- The results in Table 2 and Figure 12 show that the values of voltage and current

for operating frequencies are close i.e.

- In Table 2 for f = 30.9 Hz, Um = 151 V, Im = 2.78 A and of Figure 12a there is fm = 29.41 Hz, Um = 148 V, Im = 2.84 A;
- In table 2 for f = 50.8 Hz, Um = 219 V, Im = 1.56 A and of Figure 12b there is fm = 50.1 Hz, Um = 232 V, Im = 1.6 A;
- In table 2 for f = 60 Hz, Um = 216 V, Im = 0.75 A and of Figure 12c there is fm = 61.34 Hz, Um = 224 V, Im = 0.62 A;
- In table 2 for f = 72.2 Hz, Um = 212 V, Im = 0.97 A and of Figure 12d there is fm = 73.63 Hz, Um = 224 V, Im = 0.96 A.
- The data given in Table 2 are obtained by measuring and storing in a data log file in Excel. The waveforms in Figure 12 were obtained by measuring the voltage and current of the controller with an oscilloscope. The comparison of the data in Table 2 and Figure 12 is provided to verify the accuracy of the measured values.
- The main purpose of the paper is defined in the abstract and introduction, and it designs and implements a prototype test system for transferring of an AC motor speed controller parameters in an IoT network. The verification of the main purpose is done with the results shown in Figure 11, which shows data screen on a mobile device in which the AC motor controller parameters are transferred in the IoT network (Figure 11a) and represents a screen of the IoT Blynk cloud network (Figure 11b).

The paper provides a solution that addresses a problem that is currently relevant. In [7], [8], [9], the subject of analysis are industrial processes from a different aspect and in all of them the commitment to connecting measurement data to a cloud platform is clear. The way in which this is realized is different and depends on the capabilities and approach of the authors. Different microcomputers and different cloud platforms are used.

4. Conclusion

This paper presents an electronic system in which solutions have been designed that cover problems from both areas of electronics, i.e., process and power electronics. The electronic system is intended for measuring, monitoring, storing and transmitting the parameters of a 1-phase AC motor speed controller in an IoT network. The solution enables the visualization of input and output parameters locally on two LCD displays and remotely on an IoT device. A data log file is also provided for the measured values on a local computer and on an IoT cloud platform.

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