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3-PHASE SMART POWER METER IMPLEMENTED IN AN RF NETWORK

GOCE STEFANOV, MAJA KUKUSEVA PANEVA, SARA STEFANOVA

Abstract. In this paper are represented the results of a design and practical realization of a 3-phase smart power meter implemented in an RF network. The application is intended for data collection of the voltage and the current values in remote on standalone plants and their transmission to the main central control panel. The solution is based on the RF interface module NRF24L01, power module PEZ004 and microcontroller. Two such modules communicate in the RF connection, as transmitter (RF Slave Network) and receiver (RF Master Network). On the receiving side, the received process data is displayed on an LCD display and stored in an EXCEL© log file.

Keywords: Smart Power Meter, RF Network, Data log file

1. Introduction

The energy consumption data in industrial process plants are essential for the efficient operation of the work process. Based on such data, on the one hand the production process can be planned, and on the other hand it is possible to take adequate measures to improve efficiency and reduce energy consumption [1], [2], [3].

Built-in devices for measuring energy and power depend on the degree of development of the measurement technique in the process of realization of the industrial process. Thanks to the development of electronics, today’s energy and power measurement systems enable the measurement values of process quantities to be visualized on display, sent remotely, and stored in a file compatible for future user processing [4], [5].

On the other hand, in reality, there are some standalone industrial processes that might represent a separate entity. Often such plants are far from the Intra and Internet network of the production companies. Thus, data distribution of some process quantities, e.g., voltage, current, pressure, flow, temperature, etc., from these remote entities to the master station must be done by means of wireless communication, very likely radio frequency (RF) connection [6], [7], [8].

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 [4]. In Figure 1 a block diagram of one 3-phase smart power system for energy and power measurements in RF network is shown.

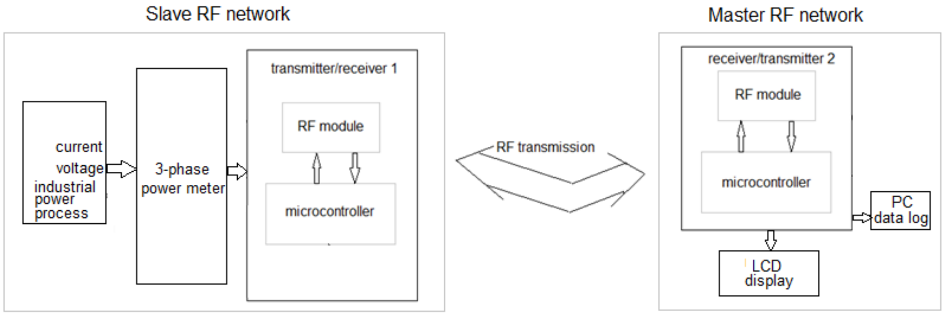


Figure.1. *Block diagram of one 3-phase smart power system for energy and power measurements in RF network*

This RF smart network consists of a Slave RF network and an RF Master Network. The Slave RF network (slave station) consists of a 3-phase power meter, an RF module and a microcontroller. The RF Master network (master station) consists of an RF module, a microcontroller and an LCD display. The solution shown in Figure 1 provides the possibility to connect the process quantities of a standalone plant in the intra network of the manufacturing company. In case the data needs to be distributed over the Internet, the Master station is upgraded with a suitable WIFI Modem as shown in the block diagram in Figure 2.

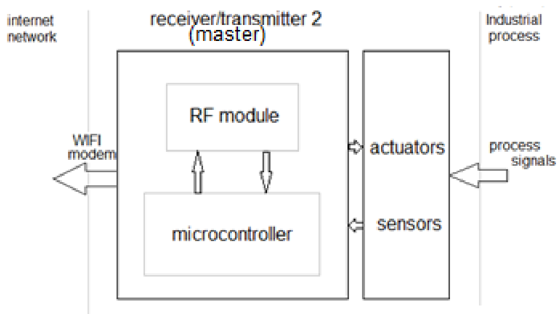


Figure 2. *Block diagram of one RF-WIFI Master station build in industrial plants*

Figure 2 shows that the proposed 3-phase smart power meter in the RF network is based on microcontrollers, RF modules and a smart power meter. The Slave microcontroller collects data such as voltage and the current values occurring in the industrial process and via RF communication sends the collected data to the Master microcontroller [5]. The Master microcomputer is connected to a personal computer through a UART port and it sends the collected data to the Intra network. This hardware architecture on the one hand provides data adequate to the conditions of the industrial process to be collected and visualized on LCD displays and on a personal computer, and, on the other hand, the possibility for distribution of data in an EXCEL© data log file.

2. Design of a 3-Phase Smart Power Meter Implemented in the RF Network

For standalone plants which are remotely positioned from the major industrial plant and lack any intra or Internet network, there is a problem with timely collection, visualization and analysis of signals from sensors that are important for the proper functionality of the industrial equipment. The designed and presented in this paper 3-phase smart power meter solves this problem and enables the integration of signals from standalone plants into the intra network. The design of this electronic device is based on a separate design of the Slave RF network and the design of the RF Master network.

2.1 Design of the Slave RF Network. In this section, the Slave RF network design process is presented. This network is based on a 3-phase power meter, a microcontroller, and the RF module NRF24L01 [5]. The designed Slave RF network has the task to measure the voltages and currents of all three phases of the remote industrial plant and it sends the measured values via RF transmission to the receiving point in the Master station.

The Slave RF network consists of three smart power modules PZEM 004T, NRF24L01 module and microcontroller Atmega 328P on Arduino nano board, as shown in Figure 3.

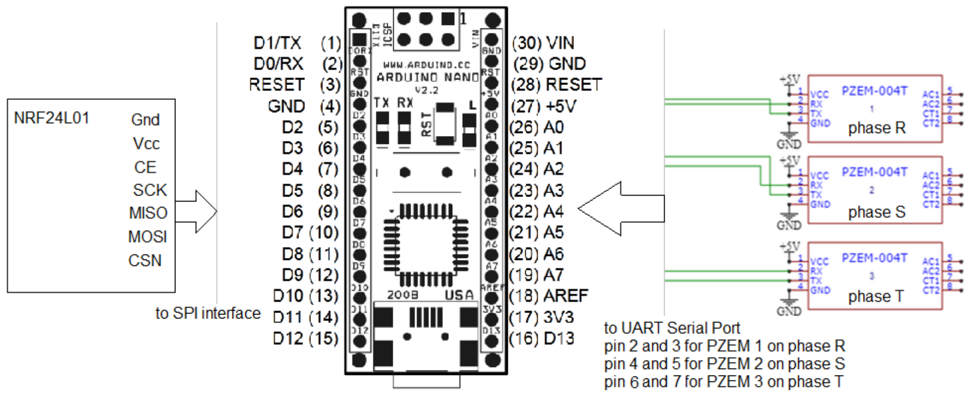


Figure 3. *Block diagram of the Slave RF Network station build in industrial plants*

The three-power meter PZEM 004T is connected by serial port on Arduino nano to pins 2 and 3 for phase R, pins 3 and 4 for phase S, and pins 5 and 6 for phase T. The RF module is connected on Arduino nano by an SPI interface (pins 8, 9, 10, 11, and 12).

2.1.1 Features of the used hardware. a) *NRF24L01 module*

NRF24L01 is a single-chip radio transceiver module that operates on 2.4 - 2.5 GHz (ISM band) [5]. This transceiver module consists of a fully integrated frequency synthesizer, power amplifier, crystal oscillator, demodulator, modulator, and Enhanced ShockBurs protocol engine. Output power, frequency channels, and protocol setup are easily programmable through an SPI interface. The built-in Power Down and Standby modes make power saving easily realizable. The electronic board on the NRF24L01 module and its pinout are presented in Figure 4.

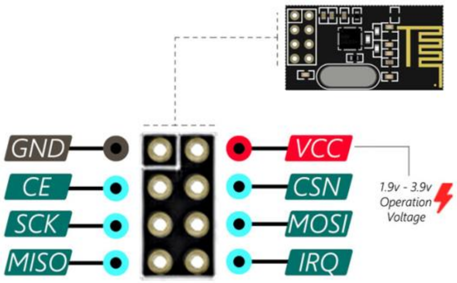


Figure 4. *Electronic board of NRF24L01 module and its pinout*

The pinout configuration of NRF24L01 module is given in Table 1.

Table 1: *Pinout configuration of NRF24L01 module*

Pin Number	**Pin Name**	**Abbreviation**	**Function**
1	Ground	Ground	Connected to the Ground of the system
2	Vcc	Power	Powers the module using 3.3V
3	CE	Chip Enable	Used to enable SPI communication
4	CSN	Ship Select Not	This pin has to be kept high always; else it will disable the SPI
5	SCK	Serial Clock	Provides the clock pulse using which the SPI communication works
6	MOSI	Master Out Slave In	Connected to MOSI pin of MCU, for the module to receive data from the MCU
7	MISO	Master In Slave Out	Connected to MISO pin of MCU, for the module to send data from the MCU
8	IRQ	Interrupt	It is an active low pin and it is used only if an interruption is required

NRF24L01 Features:

- 2.4GHz RF transceiver Module
- Operating Voltage: 3.3V
- Nominal current: 50mA
- Range: 50 – 100 m

- Operating current: 250mA (maximum)
- Communication Protocol: SPI
- Baud Rate: 250 kbps - 2 Mbps.
- Channel Range: 125
- Maximum Pipelines/node: 6
- Low-cost wireless solution

The NRF24L01 is a wireless transceiver module, meaning that each module can both send and receive data. The operating frequency is 2.4 GHz, which falls under the ISM band and hence it is legal to use in almost all countries for engineering applications. When the modules operate efficiently, this module can cover a distance of approximately 100 meters (200 feet), which makes it a great choice for all wireless remote-controlled projects.

The module operates at 3.3V hence can be easily used with 3.2V systems or 5V systems. Each module has an address range of 125 and each module can communicate with 6 other modules; so it is possible to have multiple wireless units communicating with each other in a particular area. Thus, mesh networks or other types of networks are possible using this module. Therefore, this module is an ideal choice for practical industry applications.

The NRF24L01 module works by means of SPI communications. These modules can either be used with a 3.3V microcontroller or a 5V microcontroller with an SPI port. The complete details of usage of this module through SPI are given in the data sheet below. The circuit diagram in Figure 5 shows that the module should be interfaced with the microcontroller. Although in Figure 5 the module uses a 3.3V microcontroller, it could operate equally for a 5V MCU. The SPI Pins (MISO<MOSI and SCK) are connected to the SPI pins of the microcontroller and the signal pins (CE and CSN) are connected to the GPIO pins of the MCU. There are ready-made available libraries, like the R24 Library, for interfacing this module with Arduino.

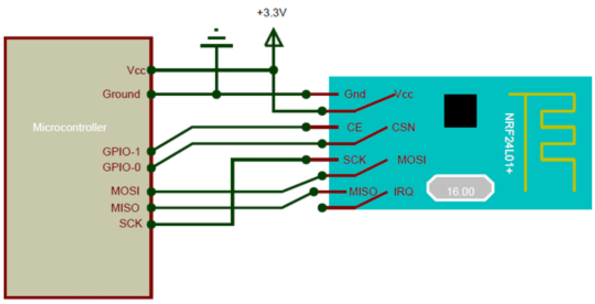
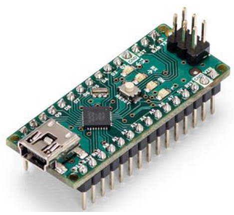
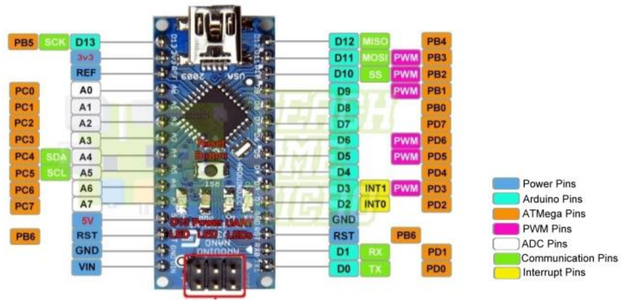


Figure 5. *NRF24L01 module interfaced with a microcontroller*

b) Microcontroller Atmega 328P. The Arduino nano is an open-source microcontroller board based on the Microchip Atmega 328P microcontroller developed by Arduino.cc. The board is equipped with sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields), and other circuits. The board has 14 digital I/O pins (six capable of PWM output), 8 analog I/O pins, and is programmable with Arduino IDE (Integrated Development Environment), via a type B USB cable. It can be powered by a USB cable or by an external 9V battery, though it accepts voltages between 7 and 20V. The Uno board is the first in the series of USB-based Arduino boards. The Atmega 328P on the board comes preprogrammed with a bootloader that allows uploading a new code to it without the use of an external hardware programmer [6]. The electronic board of Arduino nano with a built Atmega 328P microcontroller and its pinouts are presented in Figure 5a and 5b, respectively.



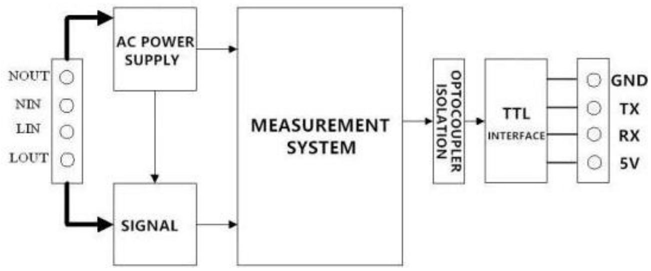


a) b)

Figure 5. *a) Arduino nano and b) pinout*

c) Power meter PZEM-004T. The power meter is mainly used for measuring AC voltage, current, active power, frequency, power factor, and active 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 an external transformer has a measuring range of 100A [7]. Figure 6a shows the board of the PZEM-004T power meter, while its block diagram is given in Figure 6b.

a)



b)

Figure 6. *a) The board of the PZEM-004T power meter, and b) The block diagram of this module.*

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

Function description

Voltage measuring range: 80～260V.

Current measuring range: 0～10A(PZEM-004T-10A);

0～100A(PZEM-004T-100A)

Active power measuring range: 0～2.3kW (PZEM-004T-10A);

0～23kW (PZEM-004T-100A)

Starting measure power: 0.4W, resolution 0.1W.

Display format: ＜1000W, displays only one decimal: 999.9W.

≥1000W, displays only integer, such as: 1000W.

Power factor measuring range: 0.00～1.00, resolution 0.01.

Frequency measuring range: 45Hz～65Hz, resolution 0.1Hz.

Active energy measuring range: 0～9999.99kWh, resolution is 1Wh.

Display format: ＜10kWh, displays unit is Wh (1kWh=1000Wh): 9999 Wh

≥10kWh, displays unit is kWh: 9999.99 kWh

Overpower alarm: Active power threshold can be set, when the measured active power exceeds the threshold, it can alarm.

Communication interface: RS485 interface.

Communication protocol

The physical layer uses UART to RS485 communication interface. The Baud rate is 9600, 8 data bits, 1 stop bit, no parity. The application layer uses the Modbus-RTU protocol to communicate. At present, it only supports function codes such as 0x03 (Read Holding Register), 0x04 (Read Input Register), 0x06 (Write Single Register), 0x41 (Calibration), 0x42 (Reset energy), etc.

0x41 function code is only for internal use (the address can be only 0xF8), used for factory calibration and return to factory maintenance occasions, after the function code to increase 16-bit password, the default password is 0x3721.

The address range of the slave is 0x01 ~ 0xF7. The address 0x00 is used as the broadcast address, the slave does not need to reply to the master. The address 0xF8 is used as the general address, this address can only be used in a single-slave environment and for calibration.

The command format of the master reads the measurement result (total of 8 bytes): Slave Address + 0x04 + Register Address High Byte + Register Address Low Byte +

Number of Registers High Byte + Number of Registers Low Byte + CRC Check High Byte + CRC Check Low Byte.

The command format of the reply from the slave is divided into two kinds: Correct Reply: Slave Address + 0x04 + Number of Bytes + Register 1 Data High Byte + Register 1 Data Low Byte + ... + CRC Check High Byte + CRC Check Low Byte Error Reply: Slave address + 0x84 + Abnormal code + CRC check high byte + CRC check low byte.

2.2 Design of the Master RF Smart Network. The Master smart network receives the data from Slave with RF communication and the values are displayed on an LCD screen and stored on a PC in a data log file compatible with MS EXCEL©.

The smart Master network consists of an NRF24L01 module, a microcomputer 328P on Arduino nano board and an LCD 2004 display.

3. Experimental results

In this section, electronic solutions for 3-phase smart power meter in an RF network and the results of their experimental work are represented.

a) Slave *RF Network.* The connection of the three phase power meters PZEM 004T at Slave RF side is given in Figure 7.

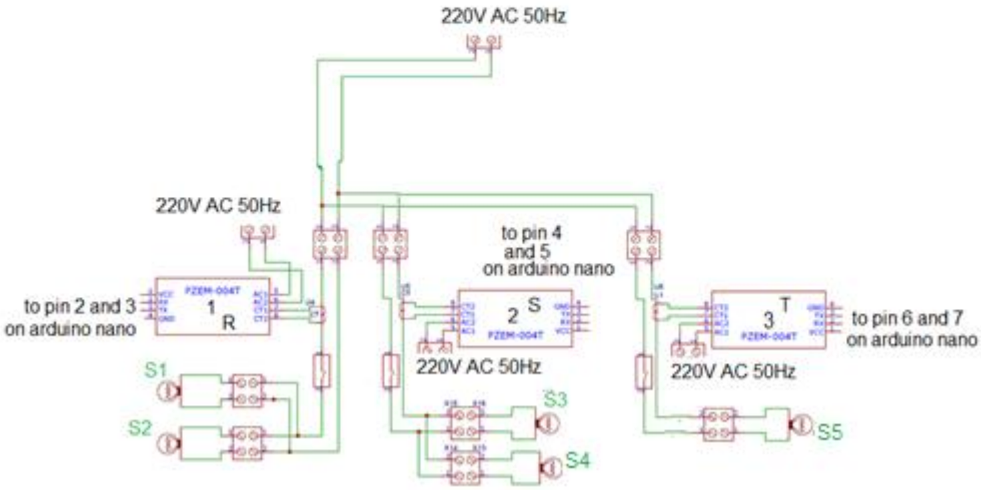


Figure 7. *Connection of three phase power meters PZEM 004T at Slave RF side*

During the testing phase, the main voltage 220V 50 Hz was used as a power supply for the three PZEM 004T power modules. Power modules are marked with 1, 2 and 3, respectively for the three phases R, S and T. Power modules measure the currents through a current transformer, and the voltage is connected to AC-AC terminals. Bulbs S1, S2, S3, S4 and S5 are used as consumers in circuit on power modules. The pins TX and RX on three power modules are connected by a serial interface by the pins 2, 3 and 4, 5 and 6, 7 on the Arduino nano.

Figure 8 shows the connection of the NRF24L01 at the SPI port (pin 8-13) with the Arduino nano [7].

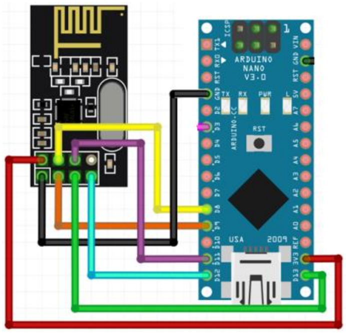


Figure 8. *The connection of the NRF24L01 at the SPI port (pin 8-12) with the Arduino nano*

The NRF module is powered by 3.3V from the Arduino nano. The experimental prototype of the Slave RF network is shown in Figure 9.

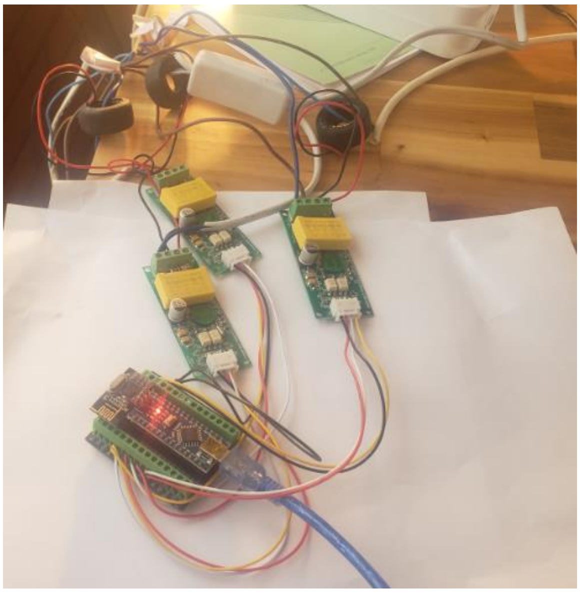


Figure 9. E*xperimental realized prototype of the Slave RF network*

As can be seen from Figure 9, at the prototype model the NRF module is placed on a case together with an Arduino nano.

b) Master RF Smart Network. Figure 10 presents the connection of the components at the Master RF side. The Master side consists of a microcontroller 328P on board Arduino nano, an NRF24L01 module and an LCD display [8].

In the master RF network of the power meter, the connection of the NRF24L01 module with the microcomputer is the same as in the RF Slave side. The difference is that the

Master side has a built-in LCD display with an I2C interface. The display is connected to the analog inputs A4 and A5 on the Arduino nano.

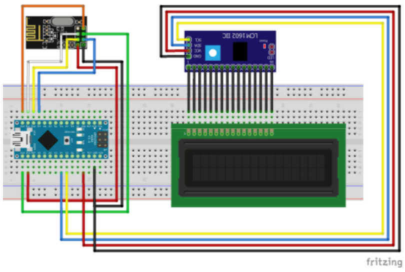


Figure 10. *The connection of the components of the Master RF side*

Figure 11 presents the experimental prototype of the Master RF network, and in Table 2 the data log file in MS EXCEL© is shown. In the data log file, the additional data for energy and frequency at all three phases are given.

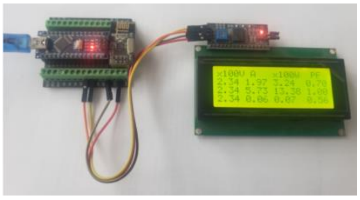


Figure 11. *Experimental results: Prototype on the Master RF network on a 3-phase smart power meter*

Table 2: *Experimental results in excel data log file*

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Date	Time	V1	I1	P1	PF1	V2	I2	P2	PF2	V3	I3	P3	PF3
2	12/2/2022	11:55:07 AM	241.3	0.45	107.4	1	241.4	0.45	107.3	1	241.5	0.05	7.3	0.55
3	12/2/2022	11:55:10 AM	241.3	0.45	107.4	1	241.3	0.45	107.2	1	241.4	0.05	7.4	0.56
4	12/2/2022	11:55:13 AM	241.4	0.45	107.5	1	241.6	0.45	107.4	1	241.7	0.05	7.4	0.56
5	12/2/2022	11:55:16 AM	241.6	0.45	107.5	1	241.6	0.45	107.5	1	241.8	0.05	7.4	0.56
6	12/2/2022	11:55:19 AM	241.4	0.45	107.5	1	241.5	0.45	107.4	1	241.7	0.05	7.3	0.55
7	12/2/2022	11:55:23 AM	241.4	0.45	107.4	1	241.6	0.45	107.4	1	241.6	0.05	7.4	0.56
8	12/2/2022	11:55:26 AM	241.5	0.45	107.5	1	241.5	0.45	107.4	1	241.7	0.05	7.4	0.56
9	12/2/2022	11:55:29 AM	241.3	0.45	107.4	1	241.3	0.44	107.2	1	241.4	0.05	7.4	0.56
10	12/2/2022	11:55:33 AM	241.4	0.45	107.4	1	241.5	0.45	107.4	1	241.6	0.05	7.4	0.56
11	12/2/2022	11:55:36 AM	241.4	0.45	107.4	1	241.6	0.45	107.4	1	241.7	0.05	7.4	0.56
12	12/2/2022	11:55:39 AM	241.3	0.45	107.4	1	241.5	0.45	107.3	1	241.5	0.06	7.4	0.55
13	12/2/2022	11:55:43 AM	241.5	0.45	107.5	1	241.6	0.45	107.4	1	241.7	0.05	7.4	0.56
14	12/2/2022	11:55:46 AM	241.5	0.45	107.5	1	241.6	0.45	107.4	1	241.7	0.05	7.4	0.56
15	12/2/2022	11:55:49 AM	241.3	0.45	107.4	1	241.4	0.45	107.3	1	241.6	0.05	7.4	0.56
16	12/2/2022	11:55:53 AM	241.5	0.45	107.5	1	241.6	0.45	107.4	1	241.8	0.05	7.4	0.56
17	12/2/2022	11:55:56 AM	241.5	0.45	107.5	1	241.6	0.45	107.4	1	241.7	0.05	7.4	0.56
18	12/2/2022	11:55:59 AM	241.5	0.45	107.5	1	241.6	0.45	107.5	1	241.8	0.05	7.4	0.56
19	12/2/2022	11:56:03 AM	241.4	0.45	107.4	1	241.5	0.45	107.4	1	241.6	0.05	7.3	0.55
20	12/2/2022	11:56:06 AM	241.3	0.45	107.4	1	241.4	0.45	107.3	1	241.5	0.05	7.4	0.56
21	12/2/2022	11:56:09 AM	241.2	0.45	107.4	1	241.3	0.45	107.3	1	241.5	0.05	7.4	0.56
22	12/2/2022	11:56:13 AM	241.3	0.45	107.4	1	241.4	0.45	107.3	1	241.5	0.05	7.4	0.56
23	12/2/2022	11:56:16 AM	241.3	0.45	107.4	1	241.4	0.45	107.3	1	241.5	0.05	7.3	0.55
24	12/2/2022	11:56:19 AM	241.2	0.45	107.3	1	241.3	0.44	107.2	1	241.4	0.05	7.4	0.56
25	12/2/2022	11:56:23 AM	241.3	0.45	107.4	1	241.3	0.44	107.2	1	241.5	0.05	7.4	0.56
26	12/2/2022	11:56:26 AM	241.2	0.45	107.3	1	241.3	0.44	107.2	1	241.4	0.05	7.3	0.55
27	12/2/2022	11:56:29 AM	241.2	0.45	107.3	1	241.3	0.44	107.2	1	241.5	0.05	7.4	0.56

The first row of the display (Figure 11) shows the values that are visualized by the power meter voltage, current, power, and power factor. The measured current values of the first phase are given in the second row, the measured current values of the second phase are given in the third row, and the measured current values in the third phase are given in the fourth row.

In Figure 12, the RF Slave and the RF Master of the 3-phase smart power meter are shown together in the test phase.

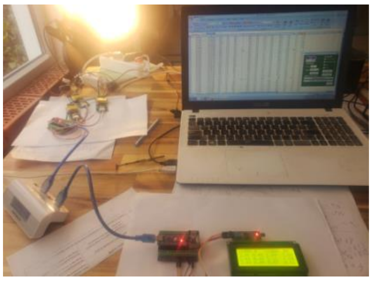


Figure 12. *Common view of the RF Slave and the RF Master of the 3-phase smart power meter in the test phase*

The designed 3-phase smart power meter in the RF network provides an opportunity to visualize the data about energy consumption in standalone plants on an LCD display, MS EXCEL© data log file and their distribution in the intra network. The accuracy and reliability of the data is confirmed by their comparison between the three measuring points LCD display and MS EXCEL© data log file.

4. Conclusion

In this paper, along with the theoretical analysis, a designed and practically realized 3-phase smart power meter implemented in RF network is presented. This smart power meter timely collections, visualization, and analysis of the energy consumption data from industrial equipment in standalone plants are presented together with the integration of these data into the intra network. Also, the data from a standalone industrial plant are transferred with RF transmission to a Master Station, visualized on the LCD screen, and stored in a data log file distributed by means of the intra network. The solution provides an opportunity for the review and analysis by the staff from the energy department of the plant to take appropriate actions in the management of electricity consumption. The designed power meter increases the availability of data relevant to the proper functioning of industrial equipment and thus increases the security and reliability of its operation.

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