GOCE DELCEV UNIVERSITY - STIP
FACULTY OF COMPUTER SCIENCE

The journal is indexed in
EBSCO

ISSN 2545-4803 on line
DOI: 10.46763/BJAMI

BALKAN JOURNAL OF APPLIED MATHEMATICS AND INFORMATICS (BJAMI)

YEAR 2024

VOLUME VII, Number 1

AIMS AND SCOPE:
BJAMI publishes original research articles in the areas of applied mathematics and informatics.

Topics:
1. Computer science;
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BALKAN JOURNAL
OF APPLIED MATHEMATICS AND INFORMATICS
(BJAMI), Vol 7

ISSN 2545-4803 online
Vol. 7, No. 1, Year 2024

EDITORIAL BOARD

C O N T E N T

Balkan Journal of Applied Mathematics and Informatics Online ISSN 2545-4803
Volume VII Number 1 Year 2024 UDC: 621.398.08:[621.396.4:004.722.4

IMPLEMENTATION OF A SCADA SYSTEM FOR REMOTE MONITORING AND POWER METERING IN RF AND IoT NETWORKS

GOCE STEFANOV AND VLATKO CINGOSKI

Abstract. This paper presents the development, design, and implementation of a SCADA monitoring power meter system for RF and IoT networks. The system collects, measures, stores, and visualizes energy data such as voltage, current, power, energy, reactive power, reactive energy, and power factor, as well as appropriate process data in two remote industrial plants. The first energy measuring point is the MASTER station and it is in the first plant, while the second energy measuring point is the SLAVE station and it is in the second plant. The SCADA monitoring system is built into the MASTER station, and the SLAVE station is connected to it by an RF radio frequency connection. Both stations contain microcomputers, energy measurement units, and appropriate RF modules. The microcomputer in the MASTER station is serially connected to the IoT microcomputer for the transfer of measurement data in the Internet network. This solution provides visualization, data log files, and transfer to the IoT network of the energy and process data from the two measuring points.

1. Introduction

Thanks to the development of electronics, today's process measurement systems enable process values to be viewed on a display, sent remotely, and stored in a file for future use. Automation and monitoring processes play a crucial role in various aspects of our lives, particularly in industrial applications [1] – [5].

Efforts are focused on ensuring reliable and simpler work, especially for operators who are directly involved in the industrial process. Energy consumption and processing data are essential for the efficient operation of industrial process plants. Based on such data, the production process can be planned, and adequate measures can be taken to improve efficiency and reduce energy consumption. The SCADA (Supervisory Control and Data Acquisition) system is used to manage and control processes, and it provides measurement, visualization, and management of all values from one place. It also allows for real-time waveforms of measured values and a data log function [6] – [8]. Some variants of modern smart systems for measuring energy consumption are considered in some studies [9], [10].

In addition to the SCADA system, a modern controlled system of an industrial process is fully rounded if it is connected to an IoT network. Such a concept enables process data to be transferred to any location, visualized in real-time, and stored on a cloud computer [11] – [13].

Date: January 17, 2024.
Keywords. SCADA,Smart Power Meter, RF Network, Data log file, IoT network

Since some standalone industrial processes are often located far from the production company's Intra and Internet network, data distribution of some process quantities such as voltage, current, pressure, flow, temperature, etc., from these remote entities to the master station must be done through wireless communication, very likely radio frequency (RF) connection [14] – [16].

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 [16]. Figure 1 shows a block diagram of a realized SCADA monitoring smart power meter implemented in IoT and RF networks.

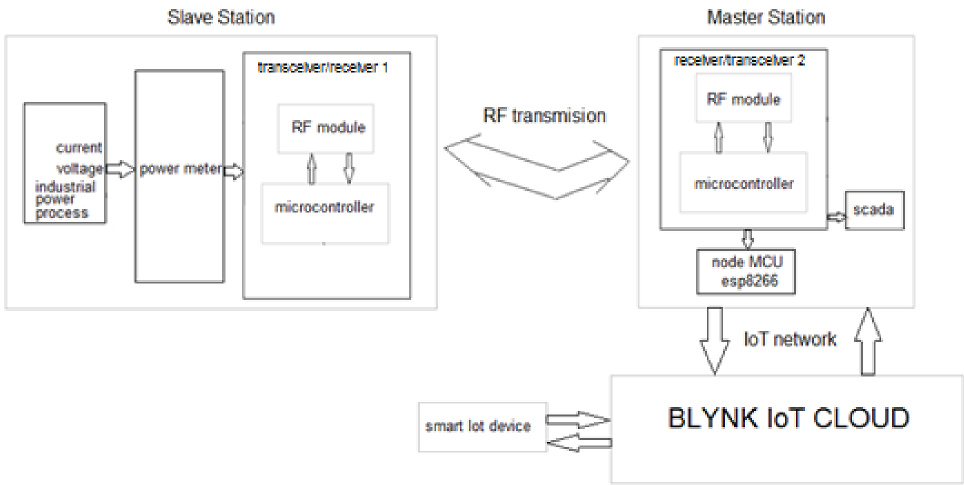


Figure 1. *Block diagram ofa SCADA monitoring smart power meter implemented in IoT and RF network*

This SCADA smart power meter consists of a SLAVE station and a MASTER station. The SLAVE station consists of a single-phase power meter, RF module, and microcontroller. The MASTER station consists of a single-phase power meter, RF module, and microcontroller. The SCADA system and IoT node MCU microcontroller are built into the MASTER station. The solution shown in Figure 1 provides the possibility to connect the process and energy quantities of two plants in the SCADA monitoring system and data transfer in the IoT network.

The SLAVE microcontroller collects data such as voltage and current values occurring in the industrial process and sends that data to the MASTER microcontroller via RF communication [5]. The MASTER microcontroller sends the collected data to the SCADA monitoring system through a UART port and is also connected to the node MCU microcontroller for data transfer in the IoT network. This hardware architecture provides the data adequate to the conditions of the industrial process to be collected and visualized in real-time on the SCADA monitoring system on a personal computer. The collected data can also be stored in an MSEXCEL© data log file and distributed in IoT cloud computers and mobile devices such as mobile phones and tablets.

This paper presents the development, design, and implementation of a SCADA monitoring power meter system for RF and IoT networks. The system collects, measures, stores, and visualizes energy data such as voltage, current, power, energy, reactive power, reactive energy, and power factor, as well as appropriate process data in two remote industrial plants. The first energy measuring point is the MASTER station and it is in the first plant, while the second energy measuring point is the SLAVE station and is located in the second plant. The SCADA monitoring system is built into the MASTER station, and the SLAVE station is connected to it by an RF radio frequency connection. Both stations contain microcomputers, energy measurement units, and appropriate RF modules. The microcomputer in the MASTER station is serially connected to the IoT microcomputer for the transfer of measurement data in the Internet network. This solution provides visualization, data log files, and transfer to the IoT.

2. Design of the SLAVE RF Station

Below is a representation of the design process for the SLAVE RF station. This station is designed for a single-phase power meter, microcontroller, and NRF24L01 RF module. Its purpose is to measure the voltages and currents of a single-phase remote industrial plant, along with four analog voltage signals from four sensors, and transmit them via RF to the MASTER station. The SLAVE RF station comprises one smart power module PZEM 004T, an NRF24L01 module, and an Atmega 328P microcontroller on an Arduino Nano board, as illustrated in Figure 2.

The power meter PZEM 004T (P1) is connected by a serial port on the Arduino Nano to pins 2 and 3. Analog signals ranging from 0 to 5V are connected on Arduino Nano analog inputs from A0 to A3, respectively. The RF module connects to the Arduino Nano by an SPI interface (pins 8, 9, 10, 11, and 12). The SLAVE RF station sends the energy data obtained by calculating the voltage and current on power meter #1 in the standalone plant, which includes V_1 - voltage, I_1 - current, P_1 - power, S_1 - apparent power, Q_1 - reactive power, E_1 - energy, Qre_1 - reactive energy, and PF_1 - power factor, as an analog voltage signal: POT1, POT2, POT3, and POT4.

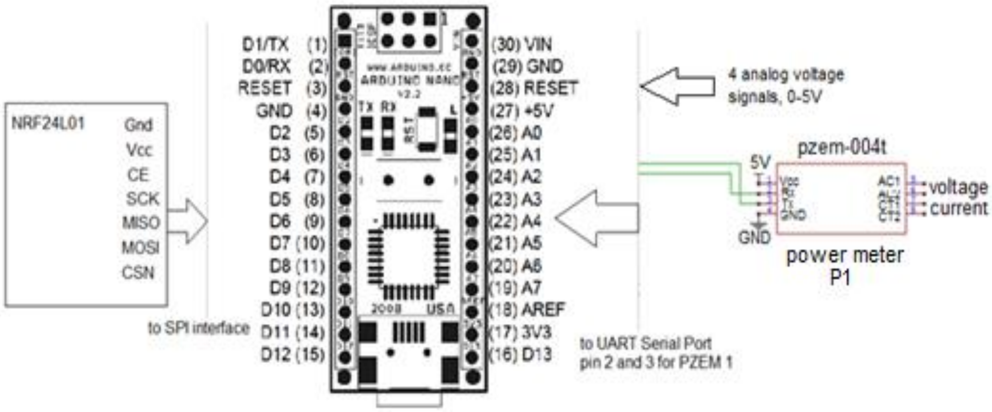


Figure 2. *Block diagram of a SLAVE RF station*

2.1 Features of the used hardware

a) ***NRF24L01 module***

The NRF24L01 is a single-chip radio transceiver module that operates on 2.4 - 2.5 GHz (ISM band) [16]. This transceiver module comprises 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. Built-in Power Down and Standby modes make power saving easily realizable. The electronic board on the NRF24L01 module is presented in Figure 3.

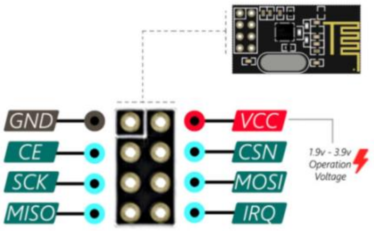


Figure 3. *The electronic board of the NRF24L01 module*

The description of the microcontroller Atmega 328P is given [18] and aNRF24L01 module is given in [16], [17].

b) Power meter PZEM-004T

The power meter is a device designed to measure various electrical parameters such as AC voltage, current, active power, frequency, power factor, apparent energy, active energy, reactive power, and reactive energy. The module does not have a display function, but the data can be read through the TTL interface. The PZEM-004T-10A built-in shunt has a measuring range of 10A, while the PZEM-004T-100A with an external transformer has a measuring range of 100A. Figure 4 shows the board of the PZEM-004T power meter.

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

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

3. Design of the MASTER RF-IoT Station

The MASTER RF-IoT station receives data from the SLAVE station via RF communication and, along with energy signals from power meter P0, displays the data on a PCSCADA screen and stores it on a PC in a data log file compatible with MS EXCEL©. The MASTER station also sends this data to the IoT network.

The MASTER RF-IoT station comprises an NRF24L01 module, an Atmega 328P microcontroller on an Arduino Nano board, and a NodeMCU ESP8266. Figure 5 shows a block diagram of the MASTER station.The MASTER station calculates energy data obtained by measuring the voltage and current in the industrial plant, which includes V_0 - voltage, I_0 - current, P_0 - power, S_0 - apparent power, Q_0 - reactive power, E_0 - energy, Qre_0 - reactive energy, and PF_0 - power factor.

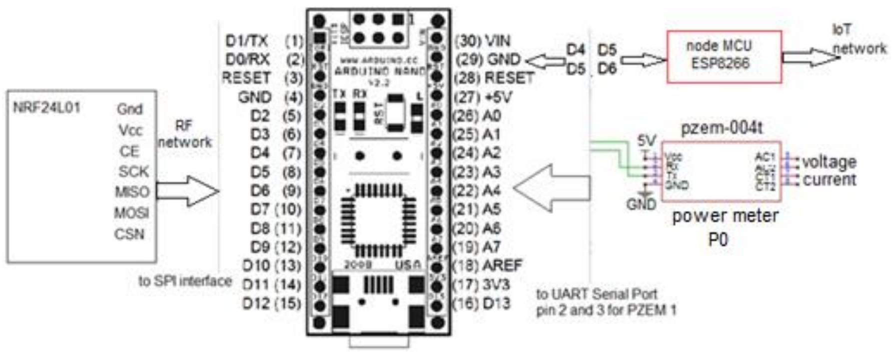


Figure 5. *Block diagram on the MASTER RF-IoT station*

The features of the Arduino Nano, NRF24L01, and PZEM-004T are described above and in [16] and [19]. Here, only the characteristics of the NodeMCU ESP8266 node will be given.

3.1 Features of the used hardware

a) *Node MCU 8266 IoT module*

The NodeMCU development board comes equipped with an ESP-12E module that features a Tensilica Xtensa 32-bit RISC microprocessor with an ESP8266 chip. This microprocessor can support RTOS and can operate at a clock frequency of 80MHz to 160MHz, which can be adjusted as per the user's requirements. NodeMCU has 128KB of RAM and 4MB of Flash memory, which makes it capable of storing data and programs. It also has built-in Wi-Fi/Bluetooth and Deep Sleep Operating features, making it ideal for the Internet of Things (IoT) projects. NodeMCU can be powered using a Micro USB jack and VIN pin (External Supply Pin) and supports UART, SPI, and I2C interfaces. Figure 6 displays NodeMCU ESP8266 and its pinout.

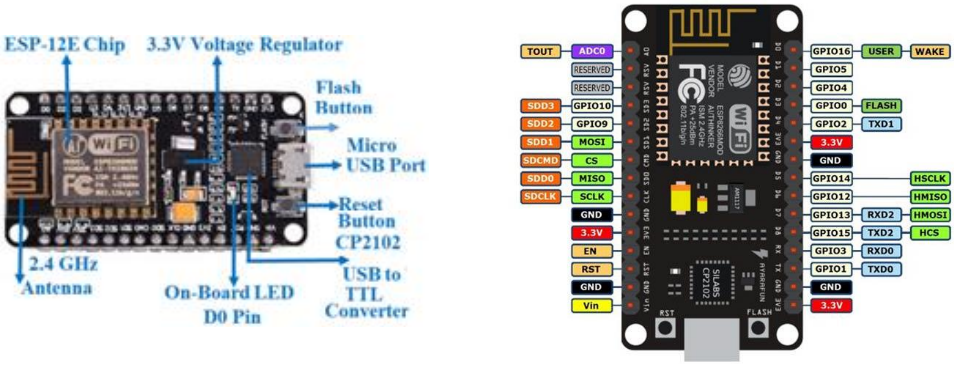


Figure 6. *NodeMCU ESP8266 and its pinout*

NodeMCU is an open-source firmware and development board specially designed for IoT-based applications. It includes firmware that is compatible with the WIFI SoC from Espressif Systems and hardware that is based on the ESP-12 module.

NodeMCU ESP8266 main specifications &features are:

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*
UARTs	*1*
SPIs	*1*
I2Cs	*1*
Flash Memory	*4 MB*

SRAM *64 KB*
Clock Speed *80 MHz*
USB-TTL based on CP2102 is included onboard, Enabling Plug-n-Play
PCB Antenna
Small Sized module to fit smartly inside your IoT projects

The NodeMCU board can be easily programmed using the Arduino IDE.

4. Design of the SCADA Monitoring System

The SCADA system is created using the Omron CX-Supervisor software [4], which is designed for PC-based visualization and machine control. It is not only easy to use for small supervisory and control tasks, but it also offers extensive power for designing sophisticated applications. CX-Supervisor has powerful functions for a wide range of PC-based HMI requirements. With predefined functions and libraries, simple applications can be created quickly, and even complex applications can be generated with a powerful programming language or VBScript. CX-Supervisor is user-friendly and intuitive, making it easy for developers to configure, test, and debug a project. It runs on standard PC desktop computers with Microsoft Windows. CX-Supervisor comprises two separate executable Windows programs: the CX-Supervisor Development environment and the CX-Supervisor Runtime environment. Figure 7 shows the connection between sensor hardware, microcontroller, and CX-Supervisor SCADA.

To set up the SCADA screen, there is a procedure that needs to be followed. First, the symbols need to be placed where the values of the measured quantities will be shown. In this case, numerical displays will be used. After that, the points need to be selected where the variables from the Arduino code will be accepted. For the MASTER station, the variables are V_0 (voltage), I_0 (current), P_0 (power), S_0 (apparent power), Q_0 (reactive power), E_0 (energy), Qre_0 (reactive energy), and PF_0 (power factor). For the SLAVE station, the variables are V_1 (voltage), I_1 (current), P_1 (power), S_1 (apparent power), Q_1 (reactive power), E_1 (energy), Qre_1 (reactive energy), and PF_1 (power factor). These variables are in the form of analog voltage signals called POT1, POT2, POT3, and POT4. Each of the numeric displays is connected to a corresponding point in the Arduino code.

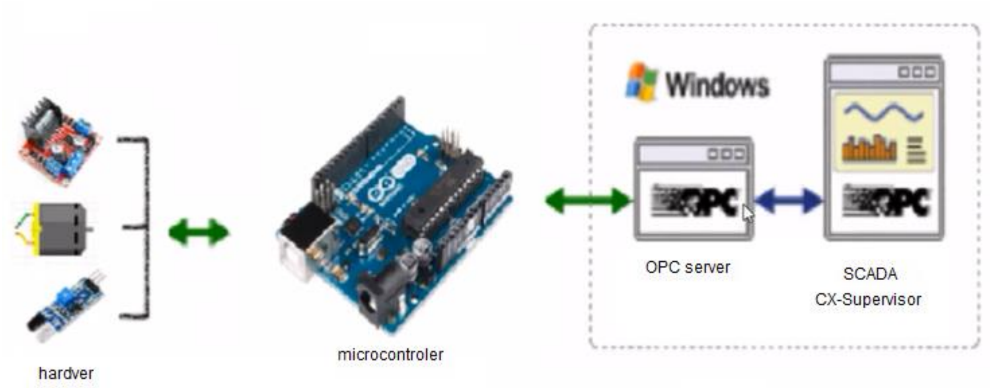
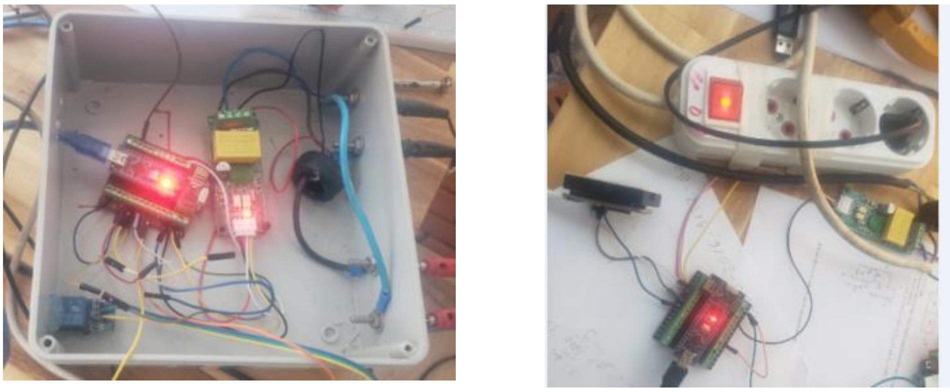


Figure 7. *Connection between sensor hardware, microcontroller, and CX-Supervisor SCADA*

5.Experimental Results

Figure 8a shows the prototype on the SLAVE station, while Figure 8b shows the prototype on the MASTER station.



a) b)

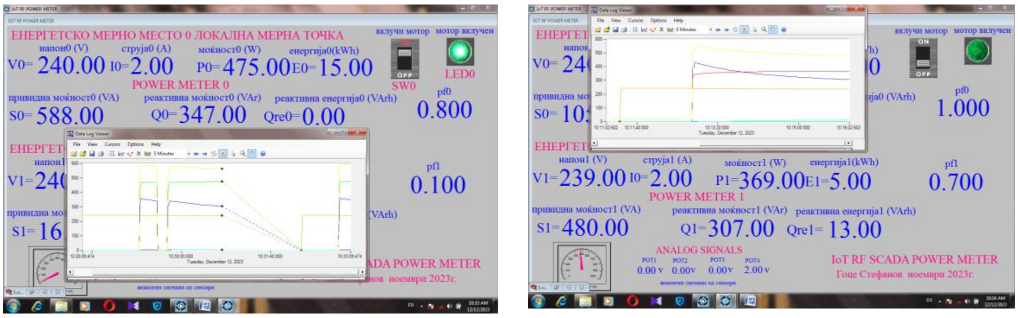
Figure 8. *Prototype on design SCADA monitoring power meter: a) prototype on SLAVE station,b) prototype on the MASTER station*

On the screen of the design SCADA monitoring power meter, you can see the information displayed in Figure 9.

Figure 9. *A screen of the SCADA design used to monitor power metering on an RF and IoT network*

Figure 9 illustrates that power meter #0 is in the MASTER station, while power meter #1 and analog signals are in the SLAVE station. In the MASTER station, switches SW0 and LED0 are responsible for controlling the values at the customer site, such as the motor and relay.

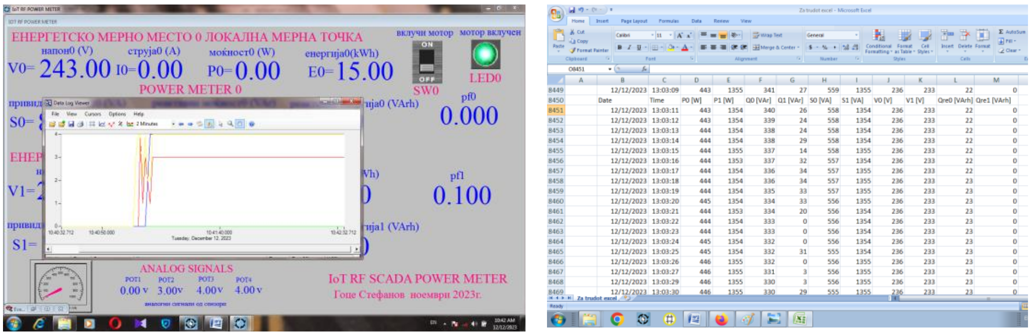
Figure 10a) displays the SCADA screen showing real-time data waveforms for power meter #0, including V_0, I_0, P_0, Q_0, S_0, and Qre_0. On the other hand, Figure 10b) shows the SCADA screen together with real-time data waveforms for power meter #1, including V_1, I_1, P_1, Q_1, S_1, and Qre_0.



a) *b)*

Figure 10. *SCADA screen together with real-time waveforms: a) for power meter #0: V_0, I_0, P_0, Q_0, S_0, and Q_{re0}, b) for power meter #1: V_1, I_1, P_1, Q_1, S_1, and Q_{re1}*

Figure 11a) shows analog signals on the SLAVE station, while Figure 11b) displays the MS EXCEL© data log file.



a) *b)*

Figure 11. *a) SCADA screen on the analog signals and waveforms in real-time, b) print screen in EXCEL© data log file*

Figure 12a) shows a data screen on a mobile device, which displays the data transferred from a SCADA smart power meter in the IoT network. On the other hand, Figure 12b) represents a screen on the IoT Blynk cloud network.

6. Analysis of results and discussion

In this paper, we explore various solutions for measuring energy consumption in different systems. Our analysis of the literature shows that the existing solutions are either specific to SCADA systems [[6] – [8],as separate solutions for energy metering of process quantities in SCADA environment [9], [10], or as separate solutions for energy meters in either standalone or IoT networks [11] – [13].

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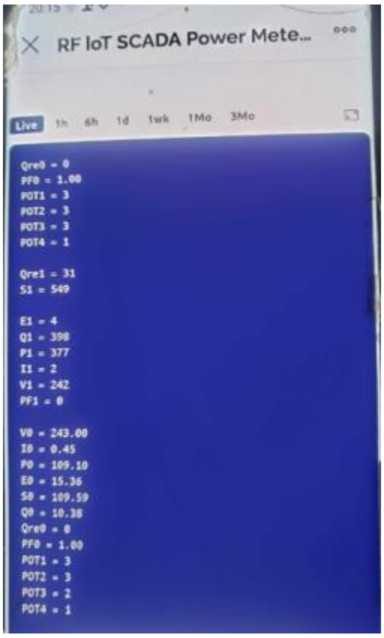

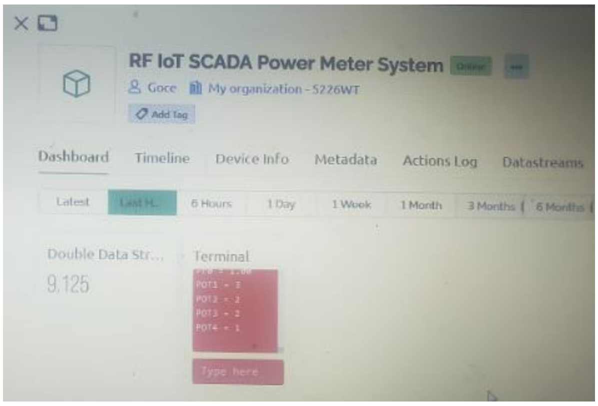

a) b)

Figure 12. *The screen on the data transferred from SCADA smart power meter in IoT network:* a) *screen on mobile device, b) screen on IoT Blynk cloud network*

However, in this paper, we propose a novel solution that integrates SCADA, power meters, and IoT systems for measuring process values and energy consumption signals. This solution also allows for the integration of data and process values as analog signals from remote industrial plants through RF communication. To validate the functionality of our proposed solution, we have implemented it practically and verified its performance through experimental results. We have included real-time waveforms of measured values and screenshots of the SCADA screen to provide visual evidence of our solution's reliability. Additionally, we have shared MS EXCEL© data log files to ensure the validity of our findings.

6. Conclusion

This paper describes a SCADA monitoring power meter that has been designed and experimentally realized in RF and IoT networks. The main purpose of this solution is to collect, measure, store, and visualize energy data (such as voltage, current, power, energy, reactive power, reactive energy, and power factor), as well as appropriate process data in two remote industrial plants known as the SLAVE and MASTER stations.

The SLAVE station is responsible for collecting data such as voltage and current values occurring in the industrial process, along with process data. This collected data is then sent via RF communication to the MASTER station. The MASTER station is connected to a personal computer through the UART port and sends the collected data to the SCADA monitoring system. Additionally, it is connected to the node MCU microcontroller for the data transfer in the IoT network.

This hardware architecture provides a real-time collection of data that is adequate to the conditions of the industrial process. The collected data can be visualized on the SCADA monitoring system on a personal computer and stored in an MS EXCEL© data log file. Furthermore, the proposed system also provides the possibility for the distribution of obtained data in IoT cloud computers and mobile smart devices (such as mobile phones and tablets).

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