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Integration of Modbus-Ethernet Communication for Monitoring Electrical Power Consumption, Temperature, and Humidity

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Abstract—**Effective management of electrical energy requires monitoring, controlling, and storing parameters gathered from power measurement devices including voltage, current, temperature, and humidity. This assessment of the quality of electrical energy is essential for management organizations, power companies, and individual consumers to develop efficient electricity usage plans. Based on the requirement, we proposed a hardware implementation for data collection and online communication software integrated with a system for collecting data on consumption of electrical energy. The EM115-Mod CT multifunction industrial meters by FINECO, the KLEA 220P three-phase multifunction meter by KLEMSAN, and the ME96SS–ver.B by MITSUBISHI are involved. Finally, the collected data of electrical consumption, temperature, and humidity can be stored on an SD card, transmitted to the cloud for real-time monitoring on mobile devices, and facilitated by the ESP-WROOM-32 microcontroller from Espressif system.**

Keywords—Espressif System; ESP32; Supervision; Data Collection; Microcontroller; Modbus Protocol via RS485 Ports.

I. INTRODUCTION

Nowadays, transmitting data from industrial meters manufactured by companies such as MITSUBISHI, KLEMSAN, and FINECO to the website has become an important issue. This capability is essential for operators who seek to monitor and propose optimal solutions for power measurement including voltage, current, temperature, and humidity in manufacturing facilities. However, the traditional methods of data transmission to the internet for monitoring incur significant costs, limiting their suitability to large corporations and the needs of small and medium-sized enterprises. Some important parameters from power measurement devices such as voltage, current, temperature, and humidity in effective management of electrical energy are required for monitoring, controlling, and storing parameters gathered from power measurement devices. This assessment of the effective management of electrical energy could be essential for management organizations, power companies, and individual consumers to develop efficient electricity usage plans.

Based on this requirement, the ESP32 microcontroller is highlighted to develop applications for data measurement and processing [1]-[4]. However, the temperature and humidity parameters have not been monitored with Modbus protocol communication with industrial meters in real-time.

In this work, we proposed a new design of Modbus-Ethernet communication system for collecting, storing data, and monitoring electrical power consumption, temperature, and humidity and communicating with industrial meters using the Modbus protocol via RS485 ports to read data from devices manufactured by companies such as KLEMSAN, MITSUBISHI, and FINECO. Finally, the electrical power consumption, humidity, and temperature parameters can be stored and transmitted directly to the cloud for real-time monitoring.

II. LITERATURE REVIEW

To describe the framework development process of effective management of electrical power consumption, temperature, and humidity, ESP32 microcontroller is highlighted to develop applications for data measurement and processing [5]-[9]. The advancements in ESP32 microcontroller, which played an important role in enhancing the overall capabilities of monitoring and data collection systems, have been coupled with the ability to connect to various devices such as sensors, amplifiers, electronic circuits, and memory cards (Micro SD) [10]-[13]. Some papers [14]-[20] have been introduced for applications using an ESP32 development board and integrated sensors adapted to work on Microsoft's Azure platform to monitor temperature and critical electrical parameters [21]-[25]. Broell et al. (2023) [26] proposed a foundation describing the connection diagram of ESP-WROOM-32 communication with the Internet. In automation for building, network communication with protocol ESP32 and ESP8266 has been used in many applications such as weather monitoring, soil moisture, and air pollution to warn of floods [27], tree growth and air pollution [28], measuring heart rate and body temperature in real time [29], and monitoring fetal heart rate [30]. Also, ESP8266 is used to control the entire process of the system for collecting data to control the vehicle on the cloud platform [31], optimizing the lighting system in the yard fly ESP32 [32], protecting farms from the intrusion of wild animals [33], developing low-cost smart remote environmental temperature monitoring system [34][35], and developing a real-time smart home monitoring system based on ESP32 and Android applications [36]-[38].

Also, the Espressif systems developed using IEEE802.11 technology for indoor environments have been designed and implemented for a smart door access system for continuous monitoring of solar PV system [39]-[42]. Users can monitor power parameters such as three-phase voltage, current, active, and reactive power remotely via a web interface helping to control energy consumption and optimize usage [43]. Management of the power consumption of an electrical cabinet can be useful to manage and choose appropriate power devices with real-time monitoring to save electrical energy and reduce costs [44]-[48].

For a powerful ESP32 microcontroller with LoRa Networks Internet of Things (IoT) connectivity, various sensors to collect environmental data [49]-[54]. The humidity and temperature parameters of the electrical cabinet are also sent to the cloud for comprehensive monitoring purposes [55]-[56]. Data is transmitted in a wireless network and stored on a central server in the cloud with IoT approach for a system framework [57]-[61]. For the automating monitoring system using IoT for environmental conditions, the system, uses integrated sensors to provide an overall view of environmental conditions, has ability to send real-time data to a remote monitoring computer via the ESP8266 platform protocol [62]-[70] and IoT and GSM Based Smart Grid Controlling and Monitoring System [71]-[78]. Recently, the integration of Modbus protocol communication with industrial meters has been reported [79][80]. However, the temperature and humidity parameters have not been monitored with Modbus protocol communication with industrial meters.

In this paper, a new design of Modbus-Ethernet communication system for collecting, storing data, and monitoring electrical power consumption, temperature, and humidity have been extended to communicate with industrial meters using the Modbus protocol via RS485 ports to read data from devices manufactured by companies such as KLEMSAN, MITSUBISHI, and FINECO. Then, the parameters such as voltage, current, power, and apparent power are recorded over time and transmitted directly to the cloud for monitoring. Finally, the electrical power consumption, humidity, and temperature parameters of the electrical cabinet are sent to the cloud for comprehensive monitoring purposes.

III. SYSTEM DESIGN

Fig. 1 shows the system connection diagram as below steps. The Power Supply serves as the primary power source providing input 220V AC and output DC 3.3V to various components of the system. The central processing is connected to the RTC, SD card, I/O, Internet, Modbus RTU, Center Processing Wifi/BLE, and the meter powered by this block. The Center Processing Wifi plays a crucial role in connecting measuring devices from different manufacturers through Modbus RTU communication. This connection allows for the monitoring of energy data from these devices. The Center Processing Wifi unit collects temperature and humidity data using I2C communication with the RTC (real-time clock) temperature sensor.

After connecting to the Internet via wireless (WiFi) or wired Ethernet, the Center Processing Wifi unit transmits data to the cloud.

This data is then displayed through a smartphone application with the Android operating system. The collected data is stored on the SD card and transmitted to the phone app for monitoring and controlling. The SD card receives data from the meter and the RTC through the Center Processing Wifi unit. Then, real-time data, which is stored based on predefined intervals on the SD card, is sent to the Center Processing Wifi unit.

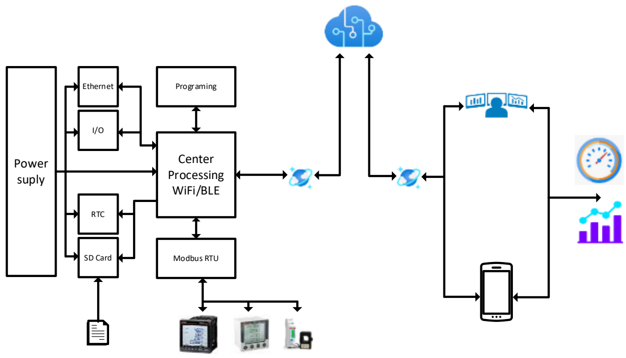

Fig. 1. System block diagram design

IV. RESULTS AND DISCUSSION

The obtained results of the design system is explained in more detail in this section. The electrical energy, temperature, and humidity data are stored and controlled by the circuit and devices as the below steps:

A. The Hardware Circuit Communicates with Measuring Devices

Fig. 2 demonstrates the stable operation of the Module Master RTU connection circuit. The module establishes connections with devices utilizing Modbus RTU. The sensor system is directly integrated into the main board to facilitate the collection of environmental data such as temperature and humidity. The real-time operating system is automatically updated. The data, which gathered from connected devices to measure temperature and humidity values, is instantly stored on the Micro SD card. The structured data on the Micro SD card is compatible with Microsoft Excel for real-time checking and data referencing. The data is efficiently transmitted through either the internal network or the Internet. The inclusion of a smartphone application significantly augments flexibility and efficiency in energy monitoring and management. This application further supports data monitoring of the system through Internet connectivity.

To check the circuit's stability. Fig. 3 illustrates the Modbus-Ethernet communication system for collecting, storing data, and monitoring electrical power consumption, temperature, and humidity installed in the cabinet. Then, it can operate very stably and yield experimental results.

Fig. 2. The circuit connects wires to the module master RTU

Fig. 3. The cabinet with the Modbus_Ethernet communication system for collecting, storing data, and monitoring electrical power consumption, temperature, and humidity parameters

B. The Algorithm Flowchart for the Board Master RTU Program

Fig. 4 illustrates the algorithm flowchart for controlling the entire system. Initially, the system retrieves data from the EEPROM to check the connection with the SD Card, and then verifies the internet connection to establish a connection with the application on the phone. Then, the connection with the RTC sensor and temperature sensor is checked. When the connection process is completed, the system proceeds to read and store data in the Cloud and the SD Card. The algorithm flowchart is explained as follows.

Block Start: The program initializes libraries, variables, constants, etc.

Block Get EEProom: this process retrieves data stored in EEPROM memory, such as WiFi user, password, the path to cloud data, the secret code for the cloud, etc. These values will be empty for the first initialization.

Block Internet Connection: This block attempts to connect to the internet. If a connection cannot be established due to an unavailable WiFi network during the first initialization, the device will broadcast a WiFi hotspot (e.g., ESP32 Reading). Users connecting to this hotspot automatically open a Captive portal (an automatic web server with an embedded HTML interface and the main program). Then, users configure system parameters on this portal, save the settings, and proceed.

Block Save EEProom: The program saves the data entered by users on the webserver into EEPROM memory and restarts the device.

Block Cloud Connection: The program attempts to connect to the Cloud database. If the connection fails due to misconfigured information or a poor connection, the device will reset after a certain period of unsuccessful attempts.

Block Void Loop: This is an infinite loop after a successful device initialization.

Block Create Data: Data is compressed from two sources following a specific structure: data collected through Modbus RTU (e.g., power parameters like voltage, amperage, frequency) and real-time data obtained from RTC (date, hour, minute, second).

Block Save SD: Before uploading to the cloud, the program saves a copy on the SD card in a predefined data structure.

Block Update Data To Cloud: Sends data to the cloud.

Block Reset Data Button: This block checks if the user pressed the reset button. If so, the program deletes specific data (e.g., WiFi account) and restarts the device, allowing users to reconfigure the device. The reset button can be configured as an external switch.

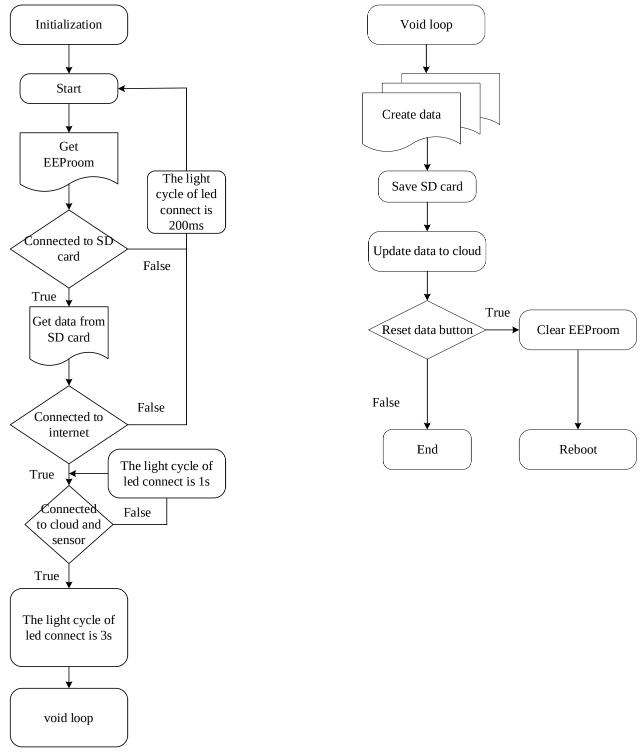

Fig. 4. The algorithm flowchart

C. *The Android Application Monitors Real-Time Electrical Parameters from the Device Online*

Fig. 5 displays a user monitoring interface in which users can easily select the device to monitor directly. It provides convenient options for connecting to measuring devices for both single-phase and three-phase electrical devices. For single-phase devices, the circuit connects to the EM115 Mod CT measuring device from FINECO. For three-phase devices, users have the option to connect to two measuring devices of either KLEA 220P from KLEMSAN or ME96SS–ver.B from MITSUBISHI based on their specific electrical usage requirements.

Then, users can select the device to monitor and confirm the choice by pressing the ACCEPT button on the interface in Fig. 5.

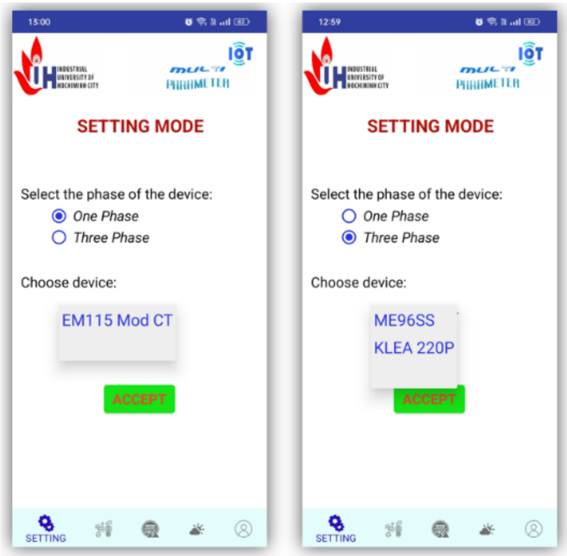

Fig. 5. System connection interface in KODULAR software for smartphone application

Fig. 6 illustrates the monitoring interface for all electrical parameters from the selected device in the interface shown in Fig. 6.

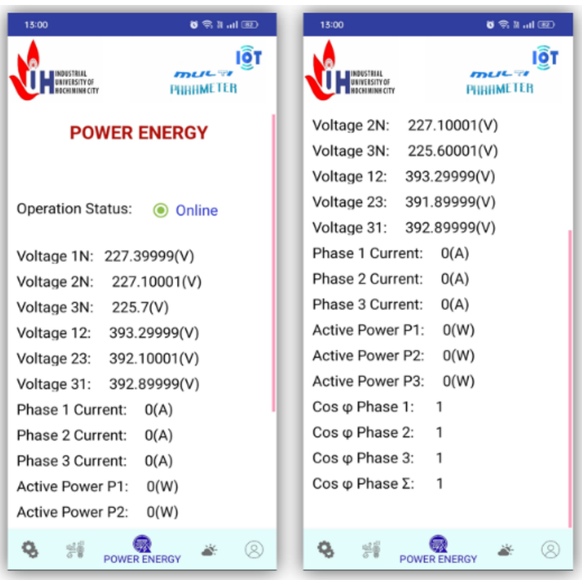

Fig. 6. The monitoring interface for electrical energy of the three-phase meter while it is operational

After pressing ACCEPT button in Fig. 5, the device starts collecting all the measured parameters in real-time. It transmits this data to the Cloud and displays all the measured parameters, such as voltage, phase angle, current, and frequency on the interface as in Fig. 6.

D. *Storing Data on the SD Card and Exporting it as an Excel File*

After selection ACCEPT button of the interface in Fig. 6, the system proceeds to store the data on the SD Card.

Fig. 7 showed step 1 to insert the micro-SD card containing the electrical parameter data from the meter into the micro-USB and plug it into the computer.

Fig. 8 showed step 2 to open Microsoft Excel and open the file with the name of the meter from which you want to export data to Excel.

Fig. 9 showed step 3 to set up the export of electrical power data from the meter to Microsoft Excel.

Fig. 10 show final step to choose the data type as General and click Finish to complete the process.

Finally, the extraction of data is collected from the measuring device and stored on the SD Card. Users can utilize this data for storage, reporting, and forecasting as a database for future artificial intelligence system integration as follows.

Step 1: Insert the micro-SD card containing the electrical parameter data from the meter into the micro-USB and plug it into the computer.

Step 2: Open Microsoft Excel and open the file with the name of the meter from which you want to export data to Excel.

Step 3: Set up the export of electrical power data from the meter to Microsoft Excel.

Final Step: Choose the data type as General and click Finish to complete the process.

After performing the data extraction in Fig. 10, Table I illustrates that the system data has been exported into an Excel file for management and use.

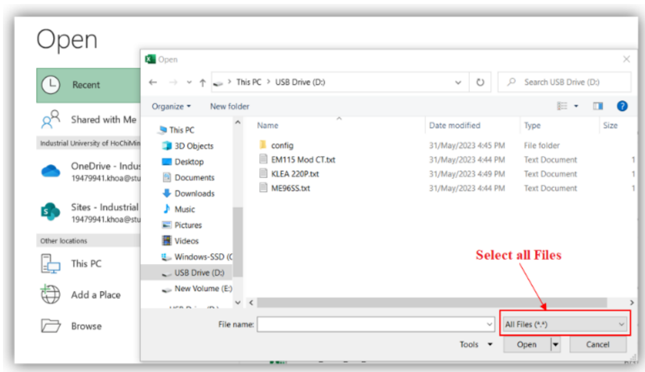

Fig. 7. Step 1: Insert the micro-SD card containing the electrical parameter data from the meter into the micro-USB and plug it into the computer

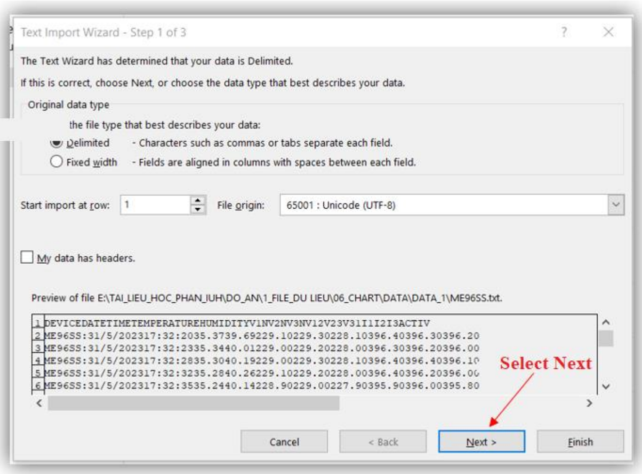

Fig. 8. Step 2: Open Microsoft Excel and open the file with the name of the meter from which you want to export data to Excel

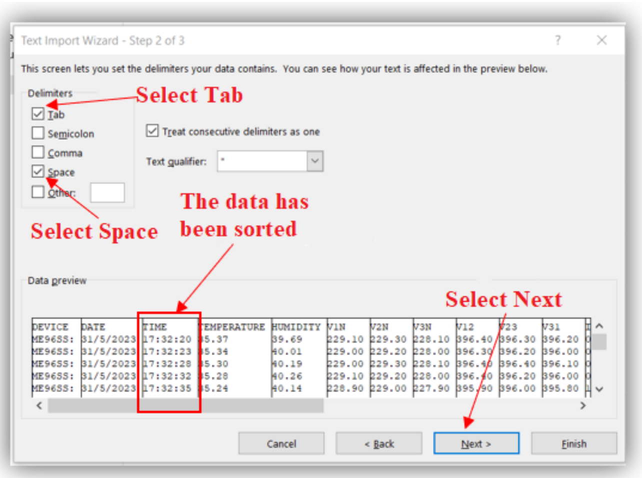

Fig. 9. Step 3: Set up the export of electrical power data from the meter to Microsoft Excel

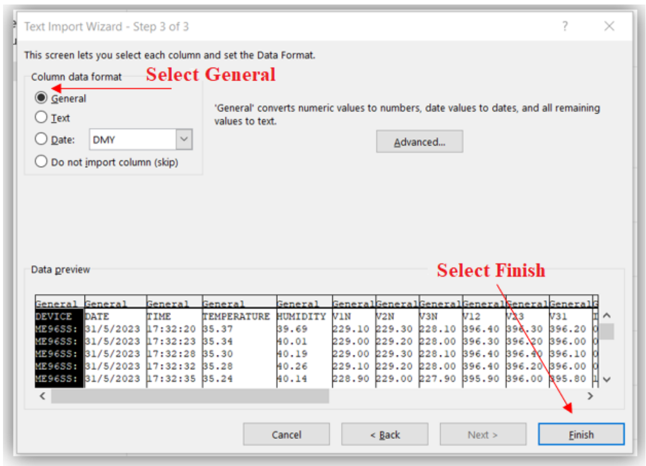

Fig. 10. Final Step: Choose the data type as general and click finish to complete the process

Fig. 11 represents the temperature data collected from Excel, presented in the form of a chart for reporting purposes. The obtained data in Table I and Fig. 11 show the real-time monitoring on temperature, humidity, and electrical power of the electrical cabinet. The temperature and humidity of the electrical cabinet are still inside the standard range of temperature (-5°C≤T≤70°C) and relative humidity (RH) (0%≤*RH*<95%), respectively.

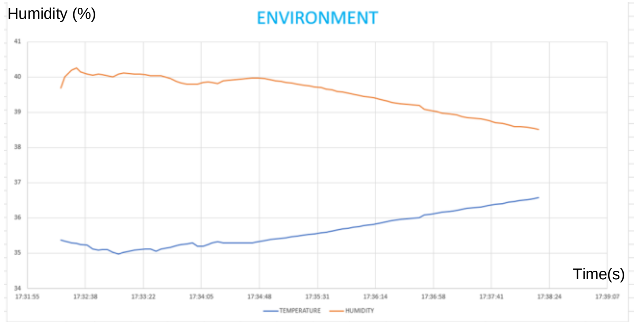

Fig. 11. The graph displaying temperature and humidity values on Excel collected by the system

TABLE I. ELECTRICAL POWER DATA FROM THE METER ON THE EXCEL SPREADSHEET

Device	Date	Time	Temperature	Humidity	V1N	V2N	V3N	V12	V23	V31	I1	I2	I3	Cosϕ1	Cosϕ2	Cosϕ3
ME96SS	31/5	17:32	35.7	39.69	229.1	229.3	228.1	396.4	396.3	396.2	0	0	0	1	1	1
ME96SS	31/5	17:32	35.34	40.01	229	229.2	228	396.3	396.4	396.1	0	0	0	1	1	1
ME96SS	31/5	17:32	35.1	40.07	228.9	229.1	227.9	396.1	395.9	395.9	1.1	0	0	0.84	1	1
ME96SS	31/5	17:33	34.98	40.09	228.9	22912	227.8	396.1	395.9	395.7	1.1	0	0	0.84	1	1
ME96SS	31/5	17:33	35.16	39.96	229.2	229.3	228	396.4	396.3	396.3	1.1	0	0	0.84	1	1
ME96SS	31/5	17:33	35.29	39.79	229.1	229.3	227.9	396.4	396.2	396.1	1.1	0	0	0.84	1	1
ME96SS	31/5	17:34	35.3	39.84	229.1	229.4	227.9	396.6	396.3	396.3	0.5	0	0	0.84	1	1
ME96SS	31/5	17:34	35.29	39.98	229.5	229.4	228.2	396.9	396.7	396.6	0	0	0	1	1	1
ME96SS	31/5	17:34	35.32	39.98	229.5	229.4	228.2	396.9	396.6	396.6	0	0	0	1	1	1

V. CONCLUSION AND FUTURE WORK

In this paper, both hardware and software components have successfully implemented for data collection and online communication within a system designed to monitor electrical power consumption. This system effectively gathers data from the EM115-Mod CT single-phase multifunctional meter by FINECO and the KLEA 220P three-phase multifunctional meter by KLEMSAN, along with the ME96SS–ver.B by MITSUBISHI. The collected data is then stored on an SD card and transmitted to the Cloud, allowing for convenient remote and real time monitoring of power parameters using Android phones without the need for on-site inspections.

In future work, the paper will focus on developments for utilizing an outlet-connected display for meter selection, monitoring circuits, and communicating data with various devices such as PLCs to the RS485 communication standard. In addition, it can be extended monitoring capabilities for variable frequency drives with RS485 communication standards. Then, the overall goal is to integrate these advancements into an artificial intelligence system for further enhancing the efficiency and intelligence of the overall monitoring and control system.

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