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IoT-Based Power Monitoring and Management System of a Distribution Substation

M. T. Alam[1], M. Ashiquzzaman[2], S. M. T. Alam[3] , M. S. Mostak[4], H. Rahman[5], and P. Das[6]
[1,2,3,4,5,6] *Department of Electrical and Electronic Engineering*
American International University- Bangladesh (AIUB), Dhaka, Bangladesh
Email- tawhidul.alam@aiub.edu, ashiquzzaman.eee@aiub.edu, tanvirul.alam360@gmail.com, mostakpiash83@gmail.com, yhasibur.rahman@gmail.com, pritomdas523@gmail.com

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***Abstract*— Remote monitoring and control of a substation is a critical issue for the power or energy management department, which is typically done manually or with the help of a costly PLC and SCADA system. With the emergence of the internet and the computational era, a smart monitoring and trustworthy controlling system over the complete sub-station is extremely desirable, which may be accomplished by implementing Internet of Things (IoT) technology. A substation contains numerous electrical components such as transformers, breakers, relays, etc. The traditional method requires a regular manual testing system with limited precision. Furthermore, substations in metropolitan settings are more difficult to physically inspect, requiring more time to complete related tasks. In this research work a monitoring system has been proposed that is low-cost, user-friendly, and works automatically to avoid labor involvement and system loss. The results of the system are displayed in many ways to ensure that the system parameters will be monitored by more than one person for safety and protection reasons. A novel feature of automatic load management system is incorporated in this project which is absent in the latest work in the literature. When load demand is increased beyond the allocated power of a particular area a priority-based load shedding is performed automatically. The project is simulated using Proteus. Besides, a small prototype has been built to monitor physical operation. The uniqueness of this system is the display of results on desktop and mobile phones simultaneously.**

Keywords*— *Internet of Things (IoT); remote monitoring; sub-station; safety and protection.

I. INTRODUCTION

By enabling the seamless integration and communication of systems, the IoT has completely changed several industries. IoT-based solutions have become an essential tool in the field of electricity distribution, especially when it comes to monitoring and managing distribution sub-stations [1]. For homes, companies, and industries to get a consistent and uninterrupted supply of electricity, sub-stations must be run effectively. In this research work, IoT-based power monitoring and management systems gather, transmit, and analyze real-time data from distribution substations using a network of electrical circuits, fire sensor, ESP32 as a communication tool, and a cloud website as a data analysis center. The performance of the equipment, as well as voltage levels, current flows, real power, and power factor, have been comprehensively shown by these systems.

The concept of connecting devices and enabling machine-to-machine communication started back in the early 1980s. It was in the 2000s when the term 'Internet of Things' was used by Kevin Ashton. Since the introduction of IoT, IoT-based power monitoring systems technology has begun to advance rapidly [2]. H. Ning and Z. Wang have made an auxiliary control system using IoT for substations [3]. They used the IEC61850 communication protocol for internal coordination and remote information transfer in the system's management and monitoring. The research contained various features such as video monitoring, security, power supply, and optimal control of sub-systems. G.Q. Tang introduced a brand-new power management system for smart grid management and visualization [4]. This research had five parts. The primary part was about grid power system failure analysis; the others were power system modeling, real-time power system monitoring, system engineering database collection, and management. J. Duncan Glover introduced a new feature to the power monitoring system by adding wireless communication using a cell phone [5]. This was also remotely accessible. Recently, Mocrii and Dragos proposed a solution for a power management system. They added physical devices embedded with electronics, software, sensors, actuators, and network connectivity [6]. E. A. Mohammed et al. developed an IoT-based three-phase substation monitoring and management system [7]. They added software titled 'Thingspaek' that is used to store the data from the substation and is used in future research and analysis. M. Paramesh *et al.* developed an IoT-based substation monitoring and controlling system [8]. Their system employs a relay for circuit protection, activating when parameters exceed predefined limits. M. Zhang *et al.* developed four modules of the smart distribution substation monitoring system, which can collect and analyze the equipment operation, environment, and security data in real time and provide early warning and automatic control functions [9]. The system is capable of reducing the feeder trip rate. K. B. Tarase and V. M. Panchade proposed a smart voltage and current monitoring system (SVCMS) that utilizes an Arduino Uno and ESP8266 Wi-Fi module for wireless monitoring of single-phase electrical systems. It also developed an Android application with MIT App Inventor 2 displays real-time voltage and current measurements [10]. O. P. Shilpi and P. Walde developed a system that triggers alarms and indicators in case of faults and displays fault details on an OLED screen. It incorporates relay control to prevent further damage. The system introduces a power supply sharing feature between two areas in case of grid failure and ensures total power cut-off during emergencies [11].

The primary objective of this research work is to measure the amount of load supplied to the consumers, to track load usage, and to measure current, voltage, real power, and power factor. The project consists of several sensors that measure the required values. An online cloud system has been integrated into the project. By using the cloud system, sub-station information can be collected remotely.

II. SYSTEM DESIGN

Automated systems are becoming more and more necessary. IoT might also be a useful tool for meeting this goal. The detailed methodology has been explained by the following discussion on the single-line diagram and flow chart of the proposed system.

A. Single Line Diagram and Flow Chart of the System

The single-line diagram and flow chart of the IoT-based power monitoring and management system for the distribution sub-station is represented accordingly in Fig. 1. and 2.

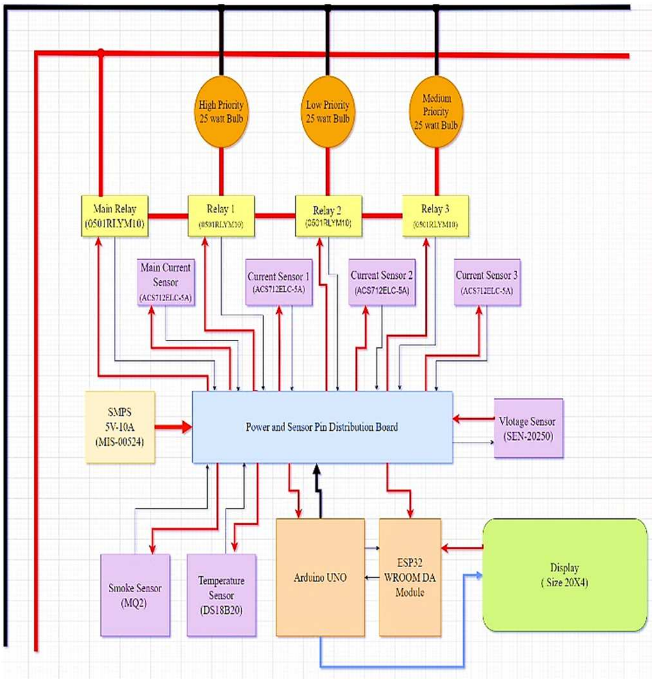


Fig. 1. Single-line diagram of the proposed system.

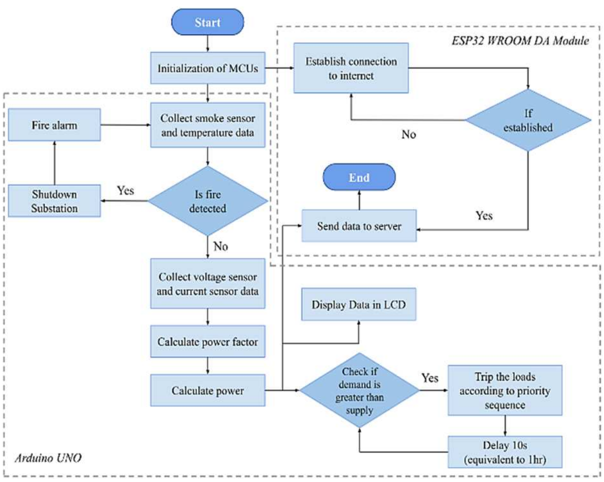


Fig. 2. Flow chart of the proposed system.

A voltage sensor is used to measure the supply voltage and a current sensor is used to measure the supply current. These can calculate the supplied power to the loads. Three more current sensors are used to measure the distributed power to the three areas mentioned in Fig. 1. Arduino Uno is used to process the values and it sends the data to ESP32. The ESP32 uploads all the information to a cloud system and is also presented to the display. A 5 V, 10 A SMPS has been used to power the sensors and the Arduino and ESP32.

III. MODELING

Modeling of the system is presented and analyzed by software simulation and hardware prototype.

A. Software Simulation

The proposed IoT-based power monitoring and management system for the distribution substation has been presented in the following simulation diagram shown in Fig. 3 constructed by Proteus.

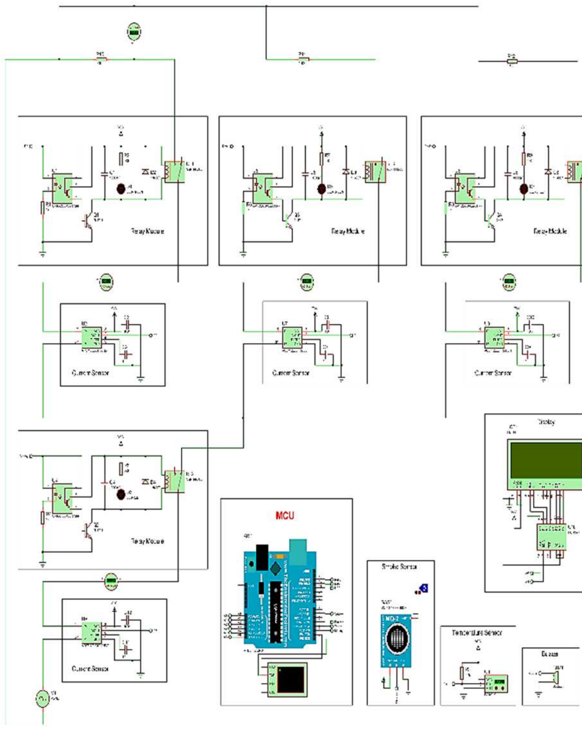


Fig. 3. Simulation model of the project using Proteus.

An Arduino Uno has been used to integrate all the components and sensors. The sensors were connected to the analog pin of the Arduino. The sensors are also connected at the load side of three areas. They measure current and voltage and give the values of current, voltage, power, and power factor. A fire sensor is used to detect the presence of fire. After processing the data, information are sent to the display unit so that the corresponding results can be monitored continuously.

B. Hardware Prototype

The proposed IoT-based power monitoring and management system for the distribution substation has been presented in the following hardware prototype shown in Fig. 4.

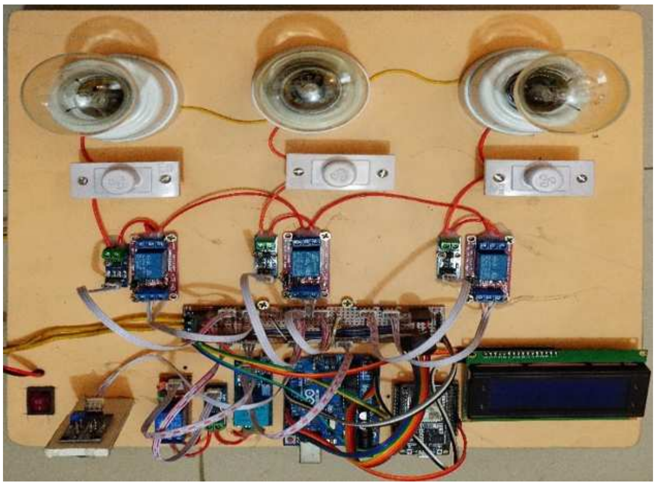


Fig. 4. Hardware setup of the proposed system.

The complete hardware setup and connection of all components and sensors of the system are represented in Fig. 4. The sensors and LCD monitor are connected to the Arduino Uno. Then the WROOM is connected to the Arduino for transferring data from Arduino Uno to the IoT server-based Cloud. The developed method is an IoT-Based Power Monitoring System that is used to measure current, voltage, power, power factor and gas. The parameters like current, voltage, power, and power factors are measured using sensors and are processed by Arduino Uno microcontroller.

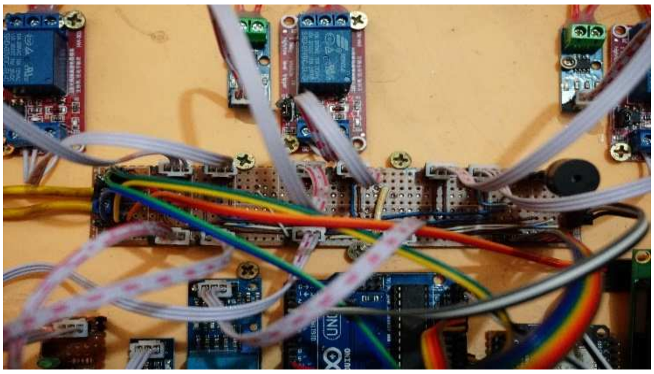


Fig. 5. Stripboard connection.

The stripboard connection of the system is represented in Fig. 5. All microcontrollers and sensors are connected in a cutting-edge stripboard by the soldering connection of the components.

C. 3D Design

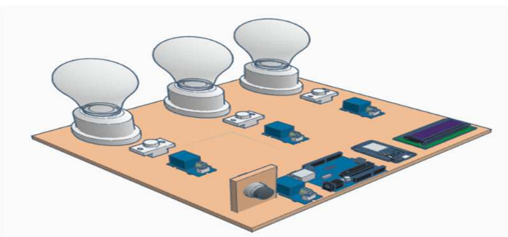


Fig. 6. 3D design model of the project.

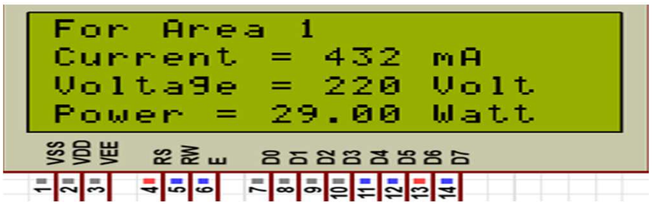
The 3D design of the proposed system is created in Fusion 360 for the Power Monitoring and Management (PMM) system and incorporates an optimized layout and integration of its components. The system includes a switch connected to a current sensor, followed by a voltage sensor. The 3D design ensures the proper placement of these components, allowing efficient routing of electrical connections and optimal space utilization. The design incorporates an interconnection between the Switch Mode Power Supply (SMPS) and a display unit. The SMPS is positioned strategically within the 3D model to efficiently convert the incoming voltage to the desired level for powering the various components of the PMM system.

IV. Result Analysis

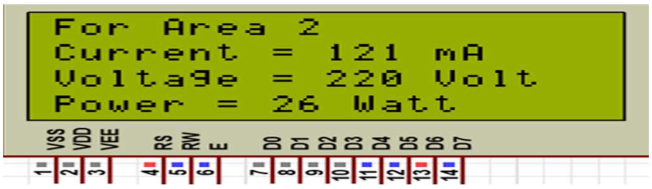
The result analysis has been completed by both software simulation and hardware simulation.

A. Simulation Result

The Fig. 7 (a), (b), and (c) show the results found in the three areas. The values are shown using a display in Proteus Software.



(a)



(b)

(c)

Fig. 7. Output of different areas:(a) Values of area 1, (b) Values of area 2, (c) Values of area 3.

After the simulation work, the display shows the voltage, current, and power values for each area. From the results shown in the display, it can be easily noted that there is 29.00 W of power for Area-1, 26.00 W of power for Area-2, and 10.00 W of power for Area-3. So, the total load capacity is 75.00 W. The maximum power for Area-1 is 30.00 W, 25.00 W for Area-2, and 20.00 W for Area-3 can be set following the total load capacity according to their demand. But, here it is noticed that Area-2 has exceeded its maximum power and the load shedding can be applied as per the capacity planned in the automation system.

B. Hardware Result

The hardware simulation, corresponding display result, and graphical presentation of the proposed system for five conditions are represented accordingly in Figs. 8 to 12. It is noted that in this developed system there is a facility for necessary load shedding and that will be implemented when the load demand of these three areas exceeded the rated total load capacity.

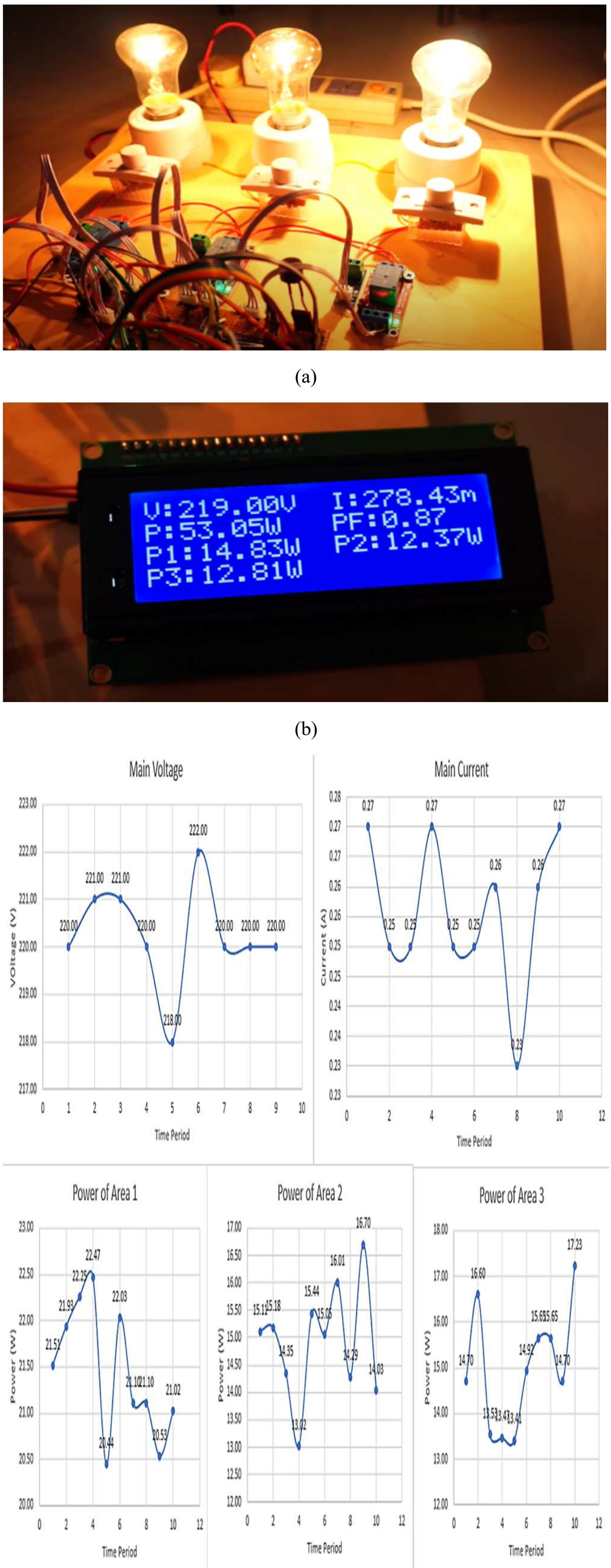


Fig. 8. Simulation at normal conditions: (a) Hardware simulation when all areas are active, (b) Display result, (c) Graphical presentation when all areas are active.

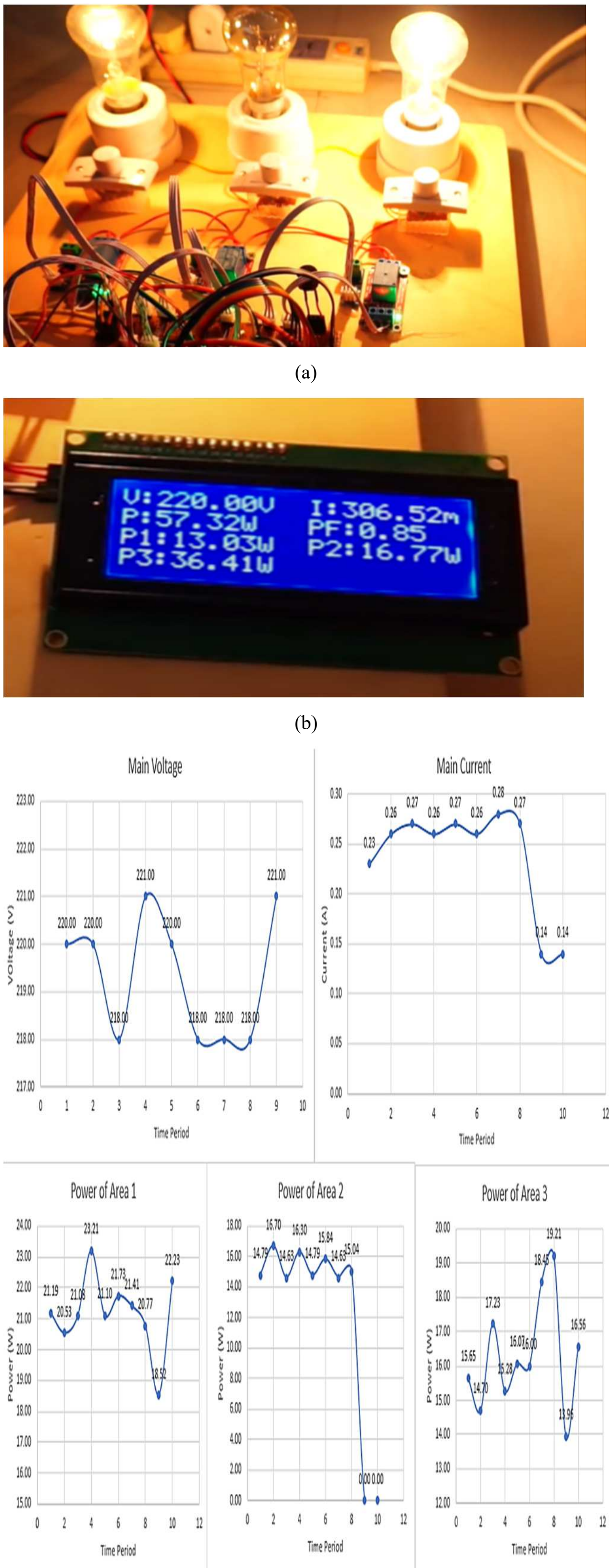
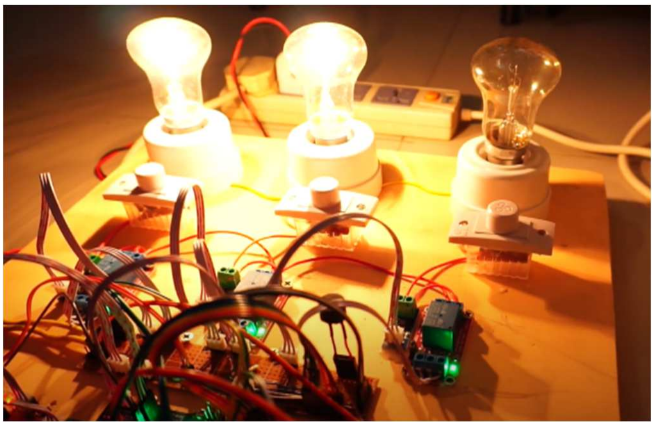


Fig. 9. Simulation at abnormal condition: (a) Hardware simulation when power is turned off at area- 2, (b) Display result, (c) Graphical presentation when power is turned off at area- 2.

In Fig. 8 (b) it can be observed that the load demand of the three areas is 53.05 W which is less than the rated total load capacity so the three areas are running as per their demand.

Fig. 9 (b) shows that the load demand is 57.32 W in three areas which has exceeded the rated load capacity of 55.00 W, so the least critical area will now have automatic load shedding and the remaining two areas will continue to operate in normal condition.



(a)

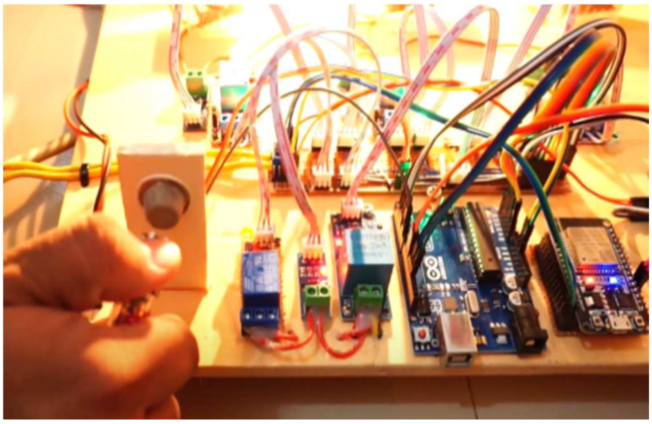
(b)

Fig. 10. Simulation at abnormal condition: (a) Hardware simulation when sequential load shedding occurred at area- 3, (b) Display result.

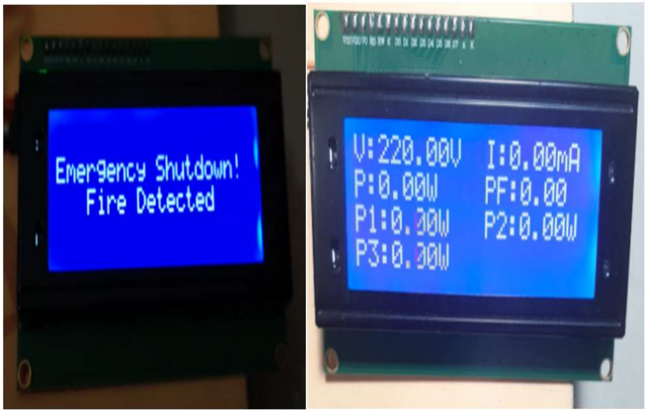
In Fig. 10 (b) it can be observed that the load shedding will occur as the total load demand exceeds the rated total load capacity but as earlier, load shedding has occurred in area-2, this time load shedding will occur in area-3 as there should not be continuous load shedding in any area at the same time.

It is seen from Fig. 11 (b) that if the system can detect fire, then automatically shut down the entire substation to avoid any accident. For that reason, no value is shown in the display.

In Fig. 12 (b) it is observed that after the fire is extinguished the entire system is reverted. This way the system can return to normal condition after solving any problem which will ensure the safety of the substation.



(a)



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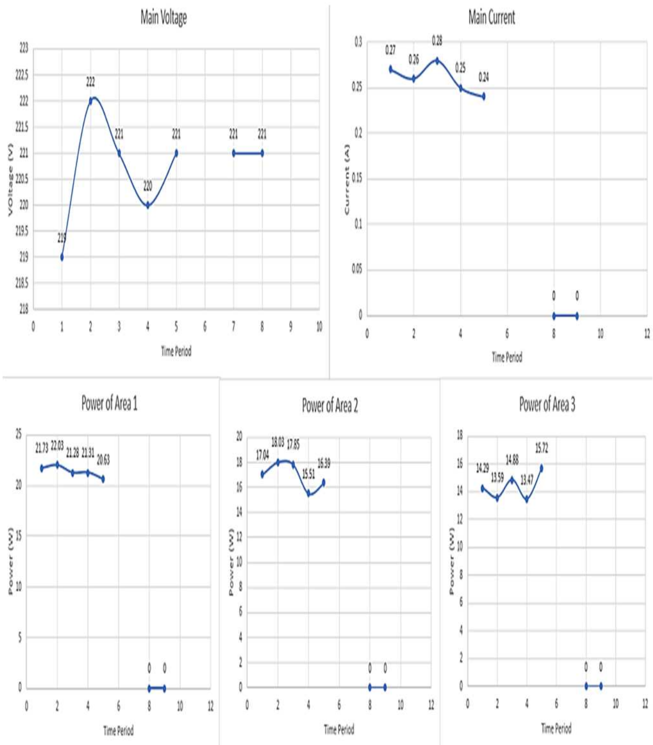
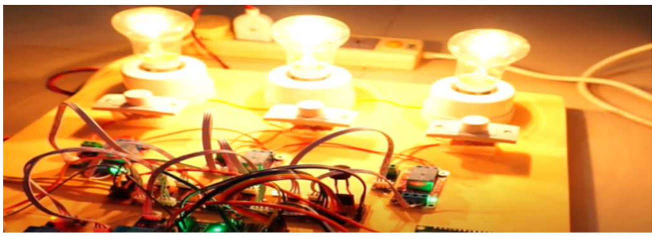


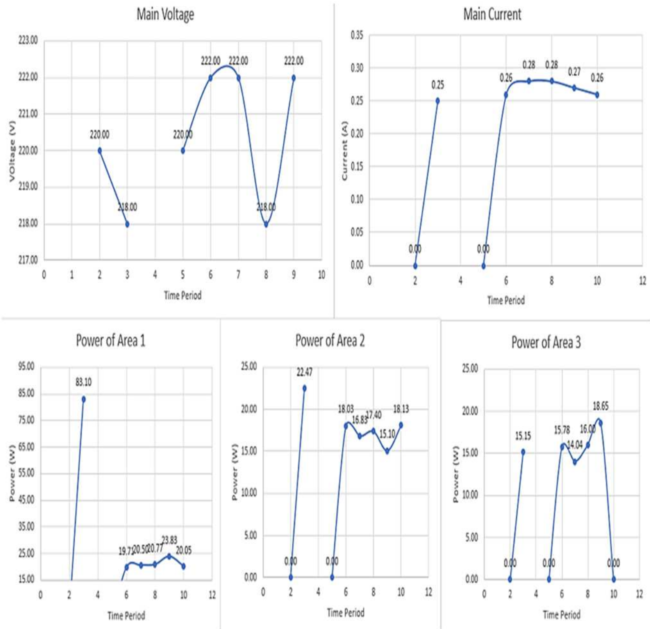
(c)

Fig. 11. Simulation at abnormal condition: (a) Hardware simulation when emergency shutdown is necessary due to fire. (b) Display result, (c) Graphical presentation when all areas are emergency shut down due to fire.



(a)

(b)



(c)

Fig. 12. Simulation at recovery condition: (a) Hardware simulation when power is needed to recover after emergency shut down (fire extinguished), (b) Display result, (c) Graphical presentation when power is needed to recover after emergency shut down (fire extinguished).

C. *Cloud System*

After processing all the data, the information is sent to ESP32, which is a Wi-Fi module used to send data and store them in a cloud system. An online cloud system has been developed that shows real-time data and can be accessed from anywhere. For monitoring the power continuously, a cloud system is very effective. The graphical presentation of Fig. 8 (c), 9 (c), 11 (c), and 12 (c) shows the real-time system. In the cloud system, the values of supplied voltage, current, and power are shown with the help of graphs. It helps for future analysis of load demand.

V. Conclusion

In this research work, an IoT-based power monitoring and management system for distribution substations has been developed. AC voltage and current sensors have been utilized to measure the required values. There is also a fire and a smoke sensor that detects the presence of fire and gas. All these sensors work through an Arduino. After processing all the data, they are sent to ESP32, which is a Wi-Fi module used to send data and store them in a cloud system effectively. An online cloud system has been developed that shows real-time data and can be accessed from anywhere. There are three areas in this system based on different types of priority. When load demand increases more than available energy, automatically load shedding happens to the lesser priority areas. A small prototype has been built to observe the hardware operation of the system. The proposed system has been simulated using Proteus software. The software simulation and prototype both have shown the values and it has worked perfectly. One of the main advantages of this system is that it is cost-effective. The cost is much lower than the existing similar type of project such as using Photon 2 in the previous research [7]. Photon is a popular device for IoT projects but it is also expensive. In this project, a low-cost microcontroller is used that can perform the same functions as Photon 2. In the future, this proposed system can be developed with different effective features such as short circuit fault analysis, three-phase system support, reactive power measurement, voltage regulation monitoring, renewable energy integration, advanced analytics for load distribution, fault prediction and prevention.

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