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Design and construction of a IoT based automated circuit breaker system

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Abstract

Electrocution is a major fatal issue faced by electricians worldwide. A Circuit breaker is a device for automatic switching of electrical devices against overload and short circuits. However, advancements in technology allow for a more sophisticated approach: the cloud-based circuit breaker with a microcontroller and sensors for monitoring the line current and voltage levels. This system switches OFF the affected line when an electrical wire becomes defective, and the lineman may safely repair it. This design integrates real-time monitoring, remote control, and internet connectivity, enhancing electrical safety and offering valuable features for modern applications. At the heart of this design lies a microcontroller (Atmega328) and Esp8266_01(Wi-Fi Module). This tiny computer chip continuously monitors the circuit using current and voltage sensors. By regulating the power supply on the electrical lines, this system protects the safety of the lineman and reduces the risk of electrocution injuries.

Keywords: IoT; ESP8266_01; Arduino Uno; Microcontroller

1. Introduction

A circuit breaker is a crucial device for the automatic switching of electrical devices, providing protection against overloads and short circuits. Electricians worldwide face significant risks of electrocution while working on faulty lines. Recent advancements in technology have introduced more sophisticated approaches, such as IoT-based smart circuit breakers that integrate real-time monitoring, remote control, and internet connectivity, significantly enhancing electrical safety and offering valuable features for modern applications.

At the heart of these systems are microcontrollers and Wi-Fi modules, continuously monitoring circuits using current and voltage sensors to ensure the safety of linemen by controlling the power supply to electrical lines. This setup maintains the control to turn the line on or off solely with the line worker, thereby enhancing safety and accountability during maintenance operations [1].

These systems also address time loss by enabling line workers to connect or disconnect the electrical line without returning to the station, optimizing the maintenance process and minimizing potential delays and disruptions, thereby improving overall productivity and operational efficiency [2].

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In recent years, the integration of Internet of Things (IoT) and wireless communication technologies has further enhanced the capabilities of circuit breaker control systems. IoT-based systems can remotely monitor and control circuit breakers, providing real-time status updates and enabling remote activation or deactivation. Additionally, these systems can incorporate features like sending automated alerts or notifications to relevant personnel in case of faults or emergencies [3].

As the demand for reliable and secure electrical systems continues to grow, the development and implementation of password-based circuit breaker control systems have become increasingly crucial. The cloud connection allows for remote control of the circuit breaker, enabling users to remotely turn circuits on or off, providing an additional layer of safety during maintenance or emergencies. This feature is particularly valuable for remotely located equipment or applications requiring frequent power cycling [4].

In this context, the concept of a password-based circuit breaker control system emerges as a powerful solution. By empowering line workers with the ability to directly control the activation and deactivation of electrical lines through a secure password-protected mechanism, these systems enhance safety, accountability, and operational efficiency during maintenance and repair activities [5].

1.1. Problem Statement

In the field of electrical power distribution, ensuring the safety of line workers during maintenance and repair operations is a critical concern. Traditional approaches to controlling circuit breakers have often lacked adequate communication and coordination between maintenance staff and electrical substation personnel. This deficiency has contributed to an alarming increase in the number of critical electrical accidents involving line workers while they are engaged in repairing electrical lines [14].

Addressing this issue is of paramount importance as it not only enhances the safety of line workers but also contributes to the overall reliability and efficiency of electrical power distribution systems. By implementing a robust solution that empowers line workers with direct control over circuit breakers while ensuring proper safety protocols, the risks associated with maintenance and repair operations can be significantly mitigated, ultimately leading to improved operational performance and increased public confidence in the electrical infrastructure [1].

Aim and Objectives of the Research

The aim of this project is to design and construct a password-based circuit breaker.

The study aims to achieve the following objectives:

- To design the system circuit diagram and simulate the system.
- To make connection between the main circuit and the other units
- To test the system functionalities
- To develop a customized cloud interface with IoT functionalities for the system

1.2. Review of Existing Works

The field of electrical power distribution is crucial for ensuring the reliable and efficient delivery of electricity to various sectors. To mitigate risks and ensure safe operations, robust protection and control mechanisms are essential.

The study by Hasan et al. [15] presents an IoT-based smart electricity monitoring and control system aimed at improving the efficiency and accuracy of household energy usage monitoring. The proposed system integrates hardware components like Arduino UNO, LCD, ACS712 current sensor, and relays, with cloud storage for data recording using ThingSpeak. A mobile application, Virtuino, provides real-time data visualization and control, significantly reducing current errors compared to traditional systems. This innovative approach facilitates better energy management and usage monitoring through IoT technologies.

Similarly, Soomro et al. [13] detail the design of an IoT-based protection system for distribution breakers using Arduino, focusing on the benefits of real-time fault detection and automated responses. These advancements reflect the growing need for intelligent, responsive electrical infrastructure in modern smart environments.

Recent advancements in intelligent maintenance systems (IMS) have significantly impacted modern manufacturing by integrating IoT, big data, and AI to enhance predictive maintenance strategies. Lee et al. [14] discuss how Prognostics and Health Management (PHM) systems provide early warnings of potential failures, optimizing maintenance schedules and reducing downtime. The study highlights the importance of Maintenance Opportunity Windows (MOWs) and system-level decision-making to improve production efficiency and minimize costs, underscoring the transformative potential of digital twins and cyber-physical systems in achieving near-zero downtime in manufacturing operations.

The preventive maintenance decision model by Zhang et al. [16] for electric vehicle (EV) charging piles utilizes mutation operators and life cycle optimization to improve maintenance efficiency and equipment lifespan, underscoring the importance of predictive strategies in maintaining EV infrastructure.

Rahman et al. [9] proposed an IoT-based smart switch using ESP32 to remotely control electrical appliances via a mobile app. The system incorporated features like scheduled on/off, timer functions, and overcurrent protection. However, security of user credentials required improvement.

Alshammari et al. [5] developed an Arduino-based smart home automation system with remote monitoring and control via SMS. While demonstrating feasibility, the study noted need for enhanced security against unauthorized access.

In recent years, the integration of IoT with traditional circuit breaker systems has led to significant advancements in electrical safety and efficiency. Authors [2] conducted a comprehensive review of IoT-based smart circuit breakers, highlighting their capabilities in real-time monitoring and remote control. The study emphasizes the enhanced protection against electrical hazards, improved energy management, and the ability to provide detailed analytics on system performance. These features make IoT-based circuit breakers a pivotal development in modern electrical infrastructure.

Sahu et al. [11] implemented a low-cost smart home system using NodeMCU and Blynk app for remote access and automation. The open-source platform proved effective yet privacy and data security required attention.

Rahman et al. [7] proposed an IoT-based smart switch using ESP8266 to remotely control and monitor electrical appliances via MQTT protocol. However, the system lacked advanced features like demand response.

Kumar et al. [6] developed an IoT-based home energy management system with renewable integration, fault detection and automated control. While demonstrating energy savings, interoperability between diverse devices posed challenges.

Sahoo et al. [10] implemented an IoT-based distribution automation system for fault sectionalizing, isolation and restoration. The distributed computing approach improved reliability but high initial costs limited adoption.

Authors [11] proposed a low-cost smart home automation kit using NodeMCU and Blynk app. The open-hardware platform offered customizability, yet security of cloud-based remote access required strengthening.

Rahman et al. [8] designed an IoT-based home energy management system with renewable integration and automated control via mobile app. Two-way communication improved efficiency although privacy of user data transmitted over the cloud remained a concern.

Stolojescu-Crisan, Crisan, and Butunoi [3] present an IoT-based smart home automation system that focuses on enhancing home security, energy efficiency, and convenience. Their system integrates various sensors and devices, enabling remote monitoring and control through a user-friendly interface. The study demonstrates the practical applications and benefits of IoT in home automation, highlighting features such as real-time data acquisition, automated control, and enhanced security protocols. This work underscores the potential of IoT technology to revolutionize modern home environments by providing smarter and more efficient solutions.

In the study by Oluwafemi, Bello, and Obasanya [4], a comprehensive design and implementation of a smart home automation system are presented. The system leverages IoT technologies to enable remote monitoring and control of home appliances. Key features include real-time data acquisition, enhanced security protocols, and user-friendly interfaces. The study underscores the significance of integrating smart technologies to improve the convenience and safety of residential environments, showcasing practical applications and potential benefits of smart home systems in modern living.

2. Materials and Methods

2.1. Review of the system Hardware and Software

2.1.1. Overview of the system Hardware

The system comprises of sensors (current and voltage) for sensing the lines/phases (RED, YELLOW AND BLUE), Atmega328 microcontroller, Wi-Fi (ESP8266_01), display unit (16*2 LCD), switching unit and power supply unit.

2.1.2. Overview of the system Software

Cloud application design and development: HTML, CSS and JavaScript was used for the user interface, they directly interact with the browser, not the Arduino. The communication between the webpage and the Arduino typically happens through JavaScript using a Web Server library on the Arduino's Wi-Fi module. Here's a general breakdown:

- Setting up the Arduino

Arduino with built-in Wi-Fi (like ESP32) or an add-on Wi-Fi module (like ESP8266) was used, and Libraries (Wi-Fi) was used to connect to Wi-Fi and create a web server.

The Arduino code defines functions to handle incoming requests (e.g., turning on the load) and send data back (e.g., sensor readings (voltage and current).

- Designing the Web Interface

HTML structures the basic webpage layout with buttons, text fields, etc.

CSS styles the visual elements of the webpage for a user-friendly interface.

JavaScript plays the key role in communication:

It sends requests (like button clicks) to the Arduino's web server using functions like fetch and libraries (XMLHttpRequest).

It receives data (like sensor readings) from the Arduino and updates the webpage elements (e.g., displaying voltage and current).

2.2. Block Diagram of the System

The block diagram shows the hardware used in the project which includes;

- Arduino Uno
- Wi-Fi Module
- Power Supply Unit
- Switching Unit
- Graphical User Interface Unit

LCD etc. as shown below.

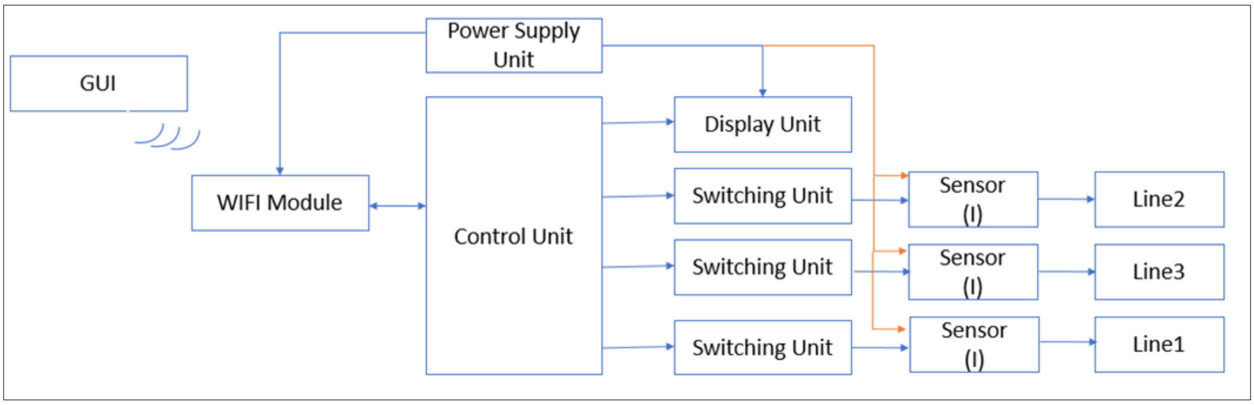

Figure 1 Block Diagram of the System

2.3. Model Setup

The system leverage Arduino Microcontroller technology and various sensors. The system operates in two distinct parts, each serving specific functions. The first part focuses on security and employs access control mechanism. The initial level utilizes a WIFI connection to establish an IP address, facilitating subsequent connections. The second level introduces an additional layer of security by requiring specified login details, which request a Password sent to the user for entry into the system. The second part of the system is dedicated to monitoring the current and voltage. It includes the detection of potential hazards, such as overcurrent identified by the current sensor and over voltage detection through the voltage sensor. Upon detecting any abnormality, the system promptly alerts the through a graphical user interface (GUI) dashboard. The entire lines status is remotely monitored using the Internet of Things (IoT) technology, facilitated by the ESP microcontroller. This grants the user a local IP, enabling wireless monitoring of the lines. Furthermore, the user can convert the local IP into a public IP through algorithms or external services like NGROK, allowing global monitoring of the system from any location.

2.4. Flow Chart of the System

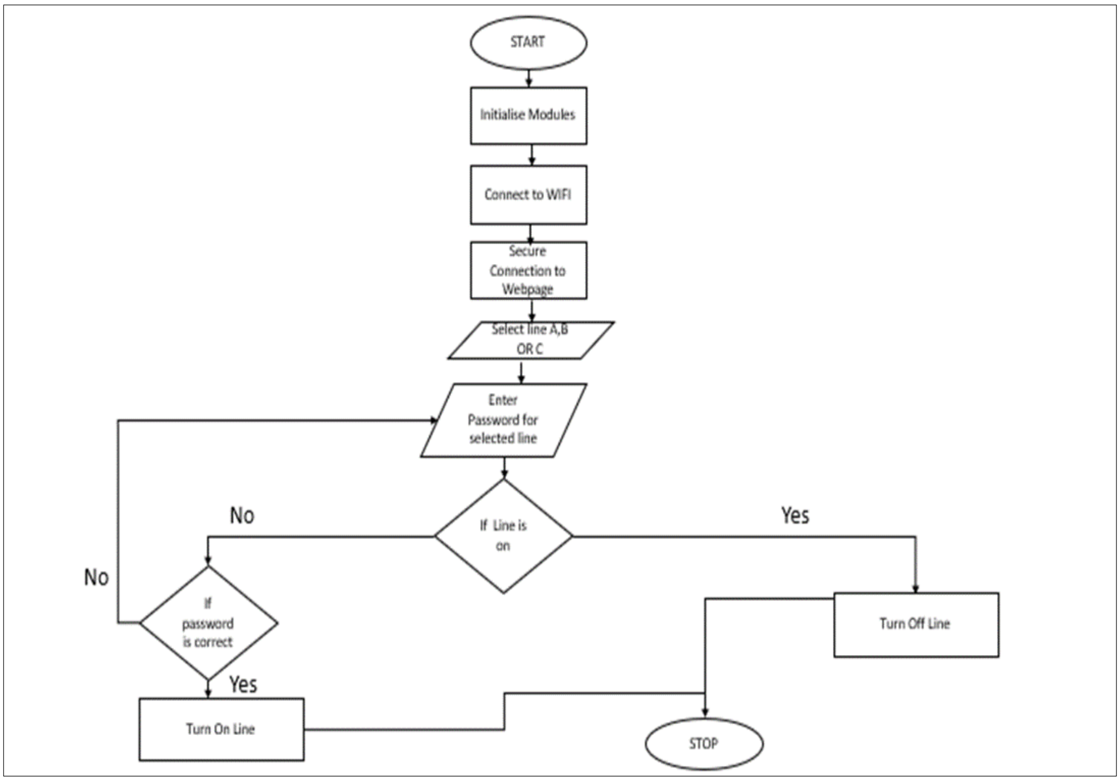

Figure 2 Flow chart of the system

This is a pictorial representation that represent an algorithm or workflow of how the software design shall be used to coordinate the hardware component of the project. This diagram shall be using several symbols with each having its intricate meaning. This is shown above.

2.5. Hardware Design of the System

The circuit diagram utilized in this project is depicted below. The hardware design process entails designing the circuitry for each functional block within the system. Three current sensors were used with each sensing a separate line. A single voltage sensor was used as this proves effective with a good result. The esp8266_01 was attached to the default universal synchronous receiver transmitter (UART) pins of the microcontroller.

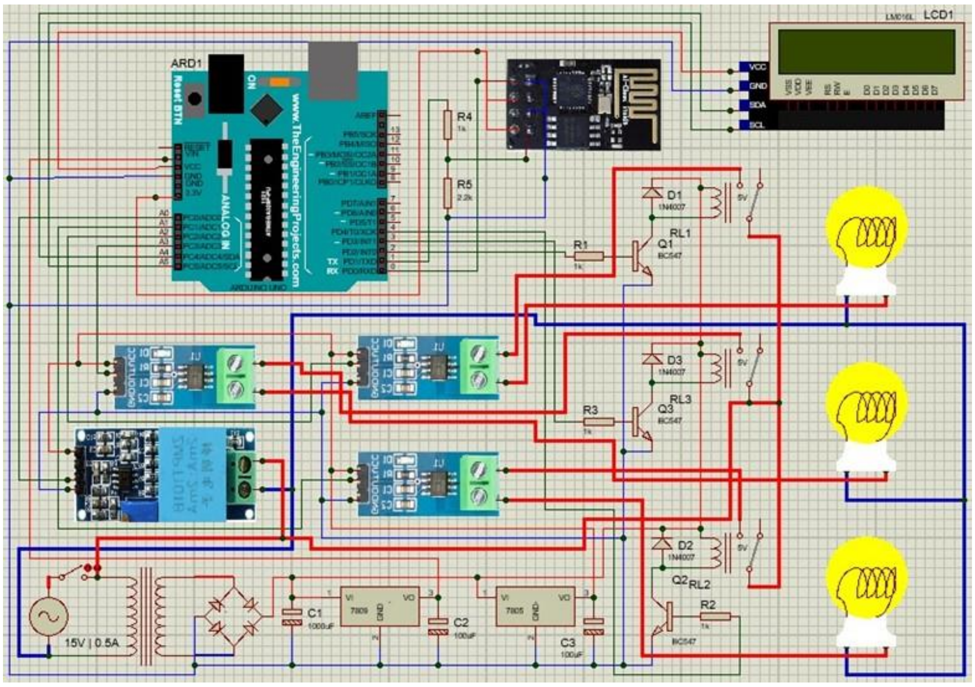

Figure 3 Circuit Diagram

3. Result and Discussion

Figure 4 Hardware Implementation Testing

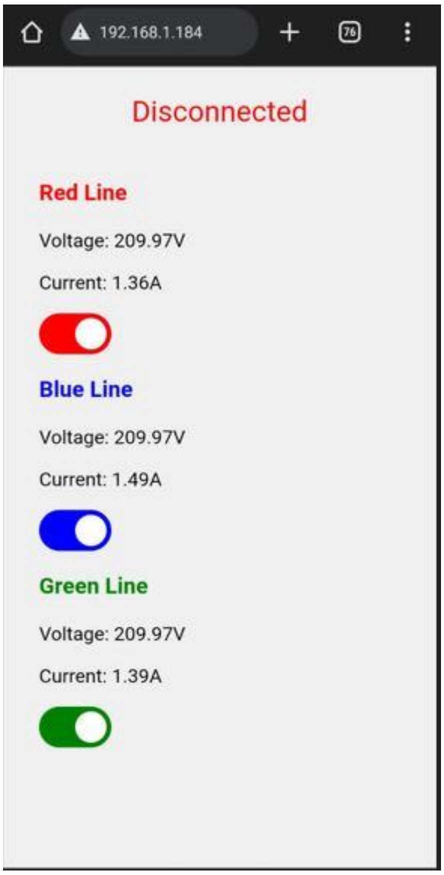

Figure 5 GUI of the Cloud interface

Testing of the Central Power Supply.

The Central power supply was targeted to supply 12V,9V and 5V. The power supply was subjected to no load and full load condition to determine the voltage regulation.

$$Voltage\ regulation\ (V.R)\ = \frac{V_{NL} - V_{FL}}{V_{NL}} \quad \text{...} (1)$$

V_{NL} = No load voltage

V_{FL} = Full load voltage

From equation 4 the voltage regulation for the central power supply is

$$V.R = \frac{18.4 - 18.1}{12.4} = \frac{0.3}{18.4} = 0.0163 = 1.63\%$$

Voltage regulators were used to provide 12Vdc, 9Vdc and 5Vdc as required by the relays, Arduino Uno and LCD/voltage sensor/current sensors respectively. The 3.3Vdc required for powering the ESP8266_01 was gotten from the onboard 3.3Vdc of the Arduino Uno. Three AC bulbs were used for testing and demonstration as showed in figure 4 above. The hardware connections were as showed in figure 3 above. The circuit diagram was sketched using proteus 8.9 software.

3.1. Cloud Application Test

In this system, the Arduino collects data such as voltage and current. The ESP8266 module creates a local network access point, allowing devices to connect without requiring an internet connection. It enables real-time communication between the Arduino and the web app via WebSocket, a protocol that allows full-duplex communication channels over a single TCP connection. The web app, built with HTML for structure, CSS for styling, and JavaScript for functionality, provides a user-friendly interface for monitoring and controlling the system. It automatically updates the display with the latest voltage and current readings received from the hardware. Figure 5 shows the application development screenshot while the interface for the software development is shown in the appendix.

The connections between the controller and cloud were via internet connections (Wi-Fi). The internet protocol (1P) address was assigned dynamically using (DHCP). This protocol allowed easy and secured communication between the systems.

4. Conclusion

The project titled "design and construction of Cloud-based circuit breaker" is a model for reducing fatal accidents with the help of Atmega328 microcontroller and cloud. For repairing the electric lines, the lineman and his safety plays a major role. Human safety is the most important factor. We have completed the project as per the requirements of our project. Finally, the aim of the project to avoid the fatal accidents for line man.

Compliance with Ethical Standards

Acknowledgment

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Disclosure of Conflict of Interest

The authors declare no conflicts of interest.

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