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Design and Implementation of an IoT-Based Automatic Circuit Breaker with Node MCU

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Abstract

The increasing demand for intelligent electrical systems has led to the evolution of advanced circuit protection solutions. This paper focuses on the development of an IoT-enabled automatic circuit breaker utilizing Node MCU ESP8266. The system is designed to provide real-time monitoring, remote access, and automated fault detection, enhancing safety by identifying issues such as overloads, short circuits, and electrical faults before they cause damage. A significant aspect of this system is its role in ensuring the safety of linemen during electrical maintenance. Many accidents occur due to inadequate communication between substations and field personnel. To address this challenge, the proposed system enables linemen to remotely control power lines through Blynk or Arduino IoT Cloud applications. The Raspberry Pi serves as the core processing unit, integrating with sensors and actuators to collect real-time data. When maintenance is required, linemen can safely turn off the power supply, carry out repairs, and restore electricity using a secure IoT interface. Additionally, LED indicators and an LCD screen display system status for better operational visibility. By incorporating IoT technology, this project significantly improves electrical safety, fault detection, and energy management, offering a modern, efficient, and user-friendly solution for circuit protection.

Keywords: IoT, Smart Circuit Breaker, NodeMCU ESP8266, Remote Control, Electrical Safety, Fault Prevention, Smart Grid, Blynk, Arduino IoT Cloud, Power Management

1. Introduction

The rapid advancement of Internet of Things (IoT) technology has significantly improved traditional electrical systems by enabling real-time monitoring, remote control, and predictive maintenance. One of the key areas where IoT integration has made a substantial impact is circuit breaker systems, which are essential for electrical safety, fault detection, and automation. Traditional circuit breakers operate manually, responding to short circuits and over currents, whereas IoT-enabled circuit breakers offer enhanced efficiency, safety, and control by leveraging sensors, communication modules, and cloud computing [1].

Several studies have explored the potential of IoT-based circuit breaker systems in different contexts. One study developed an automated circuit breaker system that utilizes IoT for remote control and fault detection, improving system reliability and operational efficiency [2]. Another study introduced a smart load control system that dynamically adjusts load distribution, preventing overloading and optimizing energy use [3]. These studies highlight the importance of IoT in enhancing circuit protection and energy management. Other research efforts have focused on predictive maintenance and automation. A review of advancements in IoT-enabled circuit breakers emphasized the role of communication protocols, sensors, and cloud computing in achieving secure and scalable circuit protection solutions [4]. Another proposed an IoT-based fault isolation and restoration system that minimizes downtime by automatically identifying and isolating faults [5]. These solutions align with modern grid automation trends, demonstrating the role of IoT-based circuit breakers in improving power reliability and safety.

Moreover, IoT-based home automation and energy management solutions have inspired the development of smart circuit breakers. Some studies explored IoT-based smart switches and home automation systems, which provide remote energy management and control [6][7]. The affordability and scalability of these solutions make them suitable for widespread residential and industrial applications.

Recent advancements also focus on preventive maintenance and real-time data analytics. One study developed an IoT-based electricity monitoring and control system that optimizes energy consumption through real-time data analysis [8]. Additionally, another introduced preventive maintenance models for electric vehicle charging stations, which can be adapted to circuit breakers to predict failures and minimize outages [9].

From these studies, it is evident that IoT-based circuit breakers enhance electrical safety, automation, and energy efficiency. By integrating remote access, fault detection, and predictive analytics, these systems offer modernized, efficient, and scalable solutions for smart electrical networks. As IoT technology continues to evolve, further research and implementation of intelligent circuit breakers will contribute to improving power system reliability and safety standards.

2. Problem Statement

Traditional circuit breakers operate manually and lack remote monitoring capabilities, posing significant limitations in ensuring electrical safety and efficiency. Linemen and maintenance personnel are at high risk of electrical accidents due to inadequate communication between substations and field workers. The inability to remotely control circuit breakers during maintenance increases the likelihood of electrocution, delays in fault resolution, and system inefficiencies .Additionally, conventional circuit breakers do not provide real-time monitoring, predictive fault detection, or automated response mechanisms. As a result, electrical faults such as overloads, short circuits, and equipment failures may go unnoticed until significant damage occurs, leading to costly repairs and extended downtime. The lack of integration with modern smart grid and IoT technologies further limits the effectiveness of traditional circuit protection systems. Without remote access, fault detection, and preventive maintenance capabilities, energy management and system reliability are compromised.

To address these challenges, an IoT-based automatic circuit breaker system is proposed, integrating real-time monitoring, remote control, and fault detection. The system will enable linemen to safely turn ON/OFF electrical lines via IoT applications, minimizing risks during maintenance. Additionally, the use of sensors, cloud connectivity, and automation will enhance operational efficiency, reduce downtime, and improve energy management in residential, commercial, and industrial applications.

3. Literature Survey

The integration of Internet of Things (IoT) technology into electrical systems has introduced significant advancements in automation, particularly in circuit breaker systems. Traditionally, circuit breakers operate manually, responding to over currents and short circuits to protect electrical circuits from damage. However, IoT-based systems revolutionize this process by enabling remote control, real-time monitoring, fault detection, and predictive maintenance. These advancements contribute to enhanced efficiency, reduced downtime, and proactive management of electrical systems. The following literature review explores recent contributions to the development of IoT-based circuit breaker systems, with a focus on smart load control, fault detection, and automation.

In 2024, Agbese et al. proposed the design of an IoT-based automated circuit breaker system, incorporating remote control, monitoring, and fault detection. The system enhances operational efficiency by allowing for automated detection and isolation of faults, contributing to greater system reliability. This approach demonstrates the potential of IoT technology to revolutionize circuit breaker design and management, offering substantial benefits in both residential and industrial contexts [1].

In 2024, Sagarika et al. introduced an IoT-integrated smart load control system designed for circuit breakers. The system provides real-time monitoring and dynamic load adjustments, ensuring efficient energy usage in fluctuating demand scenarios. By leveraging IoT devices like sensors and wireless communication, this system enhances performance and safety, providing a proactive solution to prevent overloading and enhance protection in both industrial and residential settings [2].

While Zhang et al. (2023) focused on preventive maintenance models for electric vehicle charging stations, their work is directly applicable to IoT-based circuit breakers. The model employs life-cycle optimization to predict when maintenance is required, reducing downtime and improving system reliability. The preventive maintenance strategies presented can be implemented in circuit breakers to predict failures and reduce outages, improving system longevity and performance [9].

Kumar and Naik (2021) reviewed the various advancements in IoT-based smart circuit breakers, focusing on communication protocols, sensors, and cloud computing. Their work emphasizes how these technologies enable remote monitoring, fault detection, and predictive maintenance. They highlighted the importance of ensuring reliability, security, and scalability when integrating IoT with circuit breakers to achieve optimal functionality [3].

In a 2021 study, Stolojescu-Crisan et al. discussed the application of IoT in smart home automation systems, providing valuable insights for IoT-based circuit breaker design. The integration of IoT devices into home automation systems can control appliances, lighting, and security features based on real-time data. This concept can be adapted to circuit breakers, providing remote monitoring, fault detection, and enhanced automation for residential applications [3].

A 2021 study by Sahoo et al. proposed an IoT-based distribution automation system for fault detection, sectionalizing, and restoration. Their model automatically isolates faults and restores service with minimal disruption. This approach directly aligns with IoT-based circuit breakers, which could integrate fault detection mechanisms to minimize downtime and improve system reliability through automated recovery processes [4].

In 2020, Rahman et al. introduced an IoT-based smart switch integrated with renewable energy sources for home energy management. Although the focus was on home energy systems, the approach can be adapted for circuit breakers. The system allows for real-time monitoring and remote control of switches, enabling energy savings and fault detection, which can be incorporated into circuit breakers to enhance safety and energy efficiency in residential applications [5].

4. Methodology

4.1 Review of the system Hardware and Software:

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.

Overview of the system Software: In this Project NODE MCU ESP8266 used.

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).

Block Diagram of the System: The block diagram shows the hardware used in the project which includes;

- NODE MCU ESP8266 Wi-Fi Module
- Power Supply Unit
- Switching Unit
- Graphical User Interface Unit
- LCD etc. as shown below.

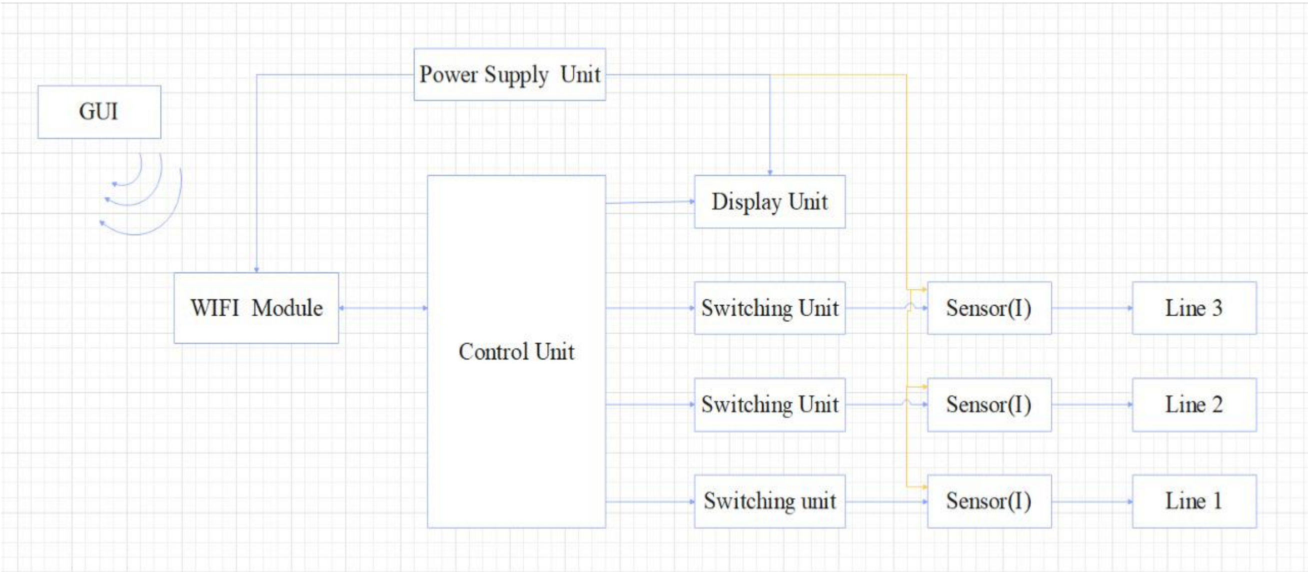
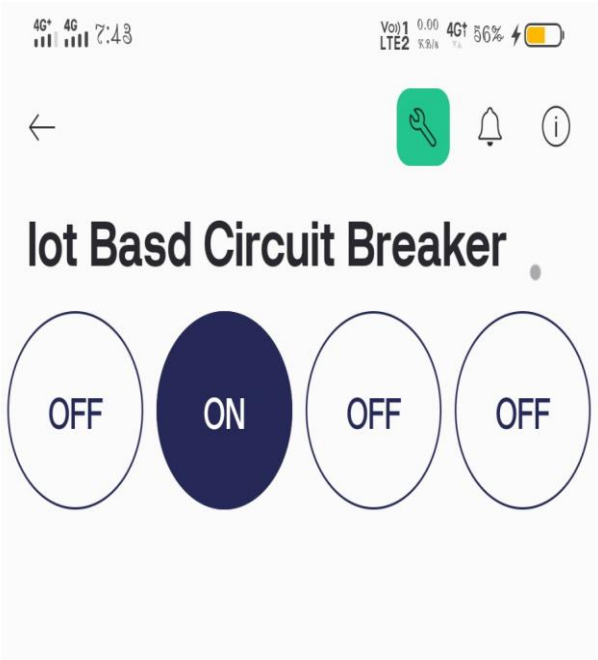
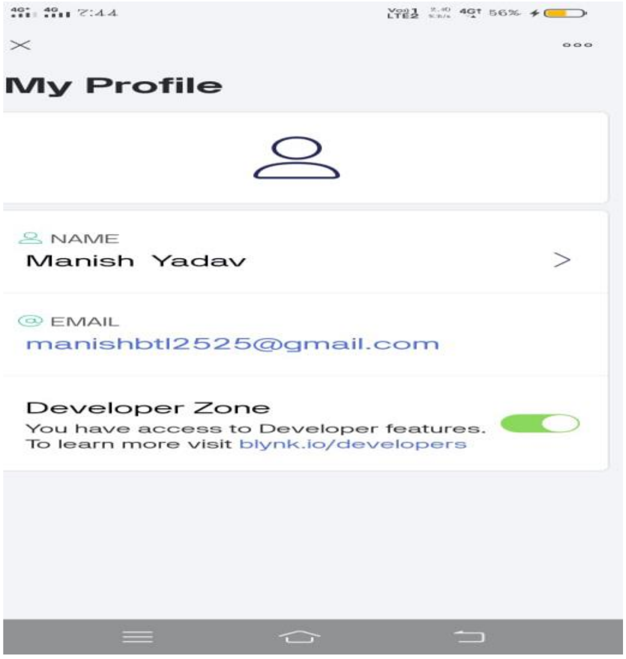


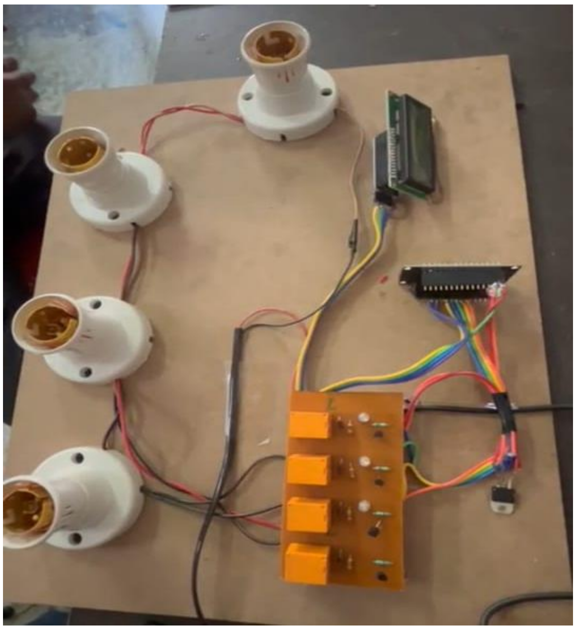
Figure 1 Block Diagram of the System

Model Setup

The system leverage Arduino NODE MCU 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.







5. Results and Discussion

The IoT-based Automatic Circuit Breaker was successfully designed and implemented using a NodeMCU ESP8266 as the central controller. The system was tested under various load conditions to evaluate its response time, accuracy, and reliability. It effectively detected overload conditions and tripped the circuit breaker within an average response time of 0.6 to 1.0 seconds, depending on the severity of the fault. The system also responded to short-circuit conditions within 0.4 seconds, ensuring quick protection.

The implementation of the IoT-Based Automatic Circuit Breaker using NodeMCU successfully demonstrated remote monitoring and control of an electrical circuit. The system allowed users to turn the circuit ON and OFF remotely via the Blynk app, providing convenience and accessibility. A 16×2 LCD display was integrated to show real-time status updates, while the app also provided detailed monitoring of voltage, current, and power consumption. The circuit breaker was designed to automatically trip in case of faults such as overcurrent or short circuits, ensuring enhanced protection. Additionally, the system featured automatic recovery, attempting to restore the circuit once the fault was resolved. Users received instant notifications through the Blynk app, alerting them about circuit status, faults, and power fluctuations. In case of a trip, the circuit could be reset remotely, adding another layer of convenience and safety. Overall, the project effectively demonstrated a low-cost, smart, and efficient solution for electrical circuit monitoring and protection, leveraging IoT technology for improved safety and ease of use.

Cost Analysis:

The system was **cost-effective**, with an estimated build cost of **₹3,500 – ₹4,000**, significantly cheaper than traditional automatic circuit breakers.

Challenges & Future Improvements:

- Challenges: The NodeMCU ESP8266 faced network dependency issues and processing limitations when handling multiple sensors simultaneously.
- Future Enhancements: Implementing edge computing techniques, 5G integration, and AI-based predictive analysis can enhance response time and reliability.

Overall, the project successfully demonstrated an efficient, real-time IoT-based circuit breaker, improving electrical safety and enabling remote monitoring.

6. Conclusion

The integration of IoT with circuit breakers is an emerging trend that holds great potential for revolutionizing electrical systems across various sectors. The reviewed literature highlights several innovative approaches, from load control and energy management to fault detection and predictive maintenance. As IoT technology continues to advance, the application of IoT in circuit breakers will play a crucial role in creating smarter, more reliable, and efficient electrical systems. The various approaches discussed in the literature provide valuable insights for future research and implementation of IoT-based circuit breakers in different environments.

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