IOT-BASED SMART CIRCUIT BREAKER CONTROL AND OTP AUTHENTICATION SYSTEM FOR LINEMAN SAFETY

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ABSTRACT

Electrical maintenance personnel, particularly linemen, are exposed to significant risks while repairing or maintaining power distribution systems due to accidental energization of electrical circuits. Miscommunication between maintenance teams and control stations or unauthorized switching operations can result in severe injuries, electric shocks, and fatalities. Conventional circuit breaker systems mainly rely on manual switching mechanisms and often lack secure authentication methods to ensure that only authorized personnel can restore power. Recent advancements in the Internet of Things (IoT), embedded systems, wireless communication, and secure authentication techniques have enabled the development of intelligent electrical safety systems for power distribution networks. This project presents an IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications. The proposed framework integrates an embedded controller, IoT communication module, relay-based circuit breaker, cloud platform, and One-Time Password (OTP) authentication mechanism to provide secure and remote control of electrical power distribution. Before energizing the power line, the authorized operator must enter a valid OTP generated by the system. The embedded controller verifies the entered OTP, and only after successful authentication is the circuit breaker allowed to switch ON or OFF. Unauthorized switching attempts are rejected automatically, thereby preventing accidental energization during maintenance activities. The IoT platform enables real-time monitoring of breaker status, authentication logs, and switching operations from remote locations. Experimental evaluation demonstrates reliable OTP verification, secure remote communication, rapid switching response, and stable system performance under different operating conditions. The proposed intelligent safety framework significantly improves lineman protection, prevents unauthorized access to electrical systems, enhances operational security, reduces maintenance-related accidents, and supports the development of secure, intelligent, and IoT-enabled smart power distribution networks.

Keywords: Internet of Things (IoT), Smart Circuit Breaker, One-Time Password (OTP), Lineman Safety, Embedded Systems, Relay Control, Electrical Safety, Remote Monitoring, Authentication System, Smart Grid.

I. INTRODUCTION

The continuous expansion of electrical power distribution networks has increased the demand for reliable maintenance and safe operation of transmission and distribution systems. Linemen play a vital role in maintaining electrical infrastructure by performing installation, repair, and fault rectification activities. However, these maintenance operations expose workers to serious electrical hazards, particularly when power lines are accidentally energized during servicing. A significant number of electrical accidents occur because of poor communication between maintenance personnel and control stations or unauthorized switching of circuit breakers. Conventional electrical distribution systems primarily rely on manual switching procedures, which may not provide adequate protection against accidental power restoration. Such incidents can lead to severe injuries, electric shocks, equipment damage, and even fatalities. Therefore, developing intelligent protection systems capable of preventing unauthorized circuit breaker operation has become an important research area. Recent advancements in embedded systems, wireless communication, authentication technologies, and the Internet of Things (IoT) provide effective solutions for enhancing electrical safety. Intelligent control systems equipped with secure authentication mechanisms ensure that electrical circuits remain isolated during maintenance activities until authorized personnel safely restore power. These technologies significantly improve workplace safety, minimize operational risks, and enhance the reliability of electrical power distribution systems [1–8].

The Internet of Things (IoT) has transformed modern industrial automation by enabling continuous communication between embedded devices, cloud platforms, and remote monitoring systems. IoT technology allows electrical equipment to exchange operational information securely through wireless communication networks, enabling real-time supervision and intelligent decision-making. In smart electrical distribution systems, embedded controllers continuously monitor breaker status, switching operations, and authentication activities while transmitting data to cloud-based monitoring platforms. Secure authentication techniques such as One-Time Password (OTP) verification further enhance operational security by ensuring that only authorized personnel can control electrical equipment. OTP authentication generates a unique password for every switching operation, preventing unauthorized access and accidental power restoration. Cloud-based monitoring also enables maintenance supervisors to observe breaker status, review authentication logs, and analyse operational history from remote locations. These technological developments improve electrical safety, reduce maintenance errors, increase operational transparency, and support the modernization of intelligent power distribution infrastructure [9–17].

This project proposes an IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications to improve electrical maintenance safety through secure authentication and intelligent remote monitoring. The proposed framework integrates an embedded controller, relay-based circuit breaker, OTP authentication module, IoT communication interface, cloud platform, and user monitoring dashboard into a unified protection system. Initially, whenever a switching operation is requested, the system automatically generates a unique One-Time Password (OTP) and sends it to the authorized operator. The entered OTP is verified by the embedded controller before any circuit breaker operation is permitted. If the OTP is valid, the relay module performs the requested switching operation. Otherwise, unauthorized switching attempts are rejected automatically, ensuring that maintenance personnel remain protected during electrical servicing. Simultaneously, all switching activities, authentication records, and breaker status information are transmitted to the IoT cloud platform for real-time monitoring and historical analysis. The effectiveness of the developed framework is evaluated using engineering parameters such as OTP verification accuracy, authentication success rate, switching response time, communication delay, system reliability, and overall operational security. Experimental evaluation demonstrates that the proposed system provides secure circuit breaker control, reliable remote monitoring, rapid authentication, and significantly improved lineman safety while supporting the development of intelligent smart grid infrastructure [18–25].

II. SURVEY OF RESEARCH

1. Smart Circuit Breaker Systems for Electrical Safety

Smart circuit breaker systems have become an important research area due to the increasing demand for safe and reliable electrical power distribution. Researchers have developed intelligent circuit breakers capable of monitoring electrical parameters and automatically controlling power flow during maintenance activities. Conventional circuit breakers mainly rely on manual switching operations, which may lead to accidental energization and serious safety hazards for maintenance personnel. Recent studies have introduced embedded controllers and intelligent protection mechanisms to improve switching accuracy and operational reliability. Automated breaker control significantly reduces human errors while improving equipment protection and electrical safety. Experimental investigations demonstrate that intelligent circuit breaker systems minimize maintenance risks, reduce equipment damage, and improve the reliability of modern electrical distribution networks [1].

2. IoT-Based Remote Monitoring in Power SystemsThe Internet of Things (IoT) has significantly improved electrical power system monitoring by enabling real-time communication between electrical equipment and cloud platforms. Researchers have integrated IoT communication modules with embedded controllers to continuously monitor breaker status, electrical parameters, and switching operations from remote locations. Cloud-based dashboards provide live visualization of equipment status while maintaining historical operating records for future analysis. Remote monitoring allows maintenance engineers and utility operators to supervise electrical infrastructure without remaining physically present at the installation site. Experimental studies confirm that IoT-enabled monitoring improves operational efficiency, reduces maintenance time, and enhances the reliability of smart electrical distribution systems. These developments demonstrate the importance of IoT technology in future smart grid applications [2].

3. OTP-Based Authentication for Secure Electrical ControlSecure authentication has become an essential requirement for preventing unauthorized access to critical electrical infrastructure. Researchers have proposed One-Time Password (OTP) authentication systems to improve the security of electrical switching operations. OTP-based authentication generates a unique password for each operation, ensuring that only authorized personnel can access or control electrical equipment. Unlike conventional password systems, OTP authentication provides higher security because each generated password is valid for only a single operation. Embedded controllers verify the entered OTP before permitting breaker operation, preventing accidental or unauthorized switching. Experimental investigations demonstrate that OTP-based authentication significantly improves electrical safety, enhances operational security, and reduces unauthorized access to power distribution systems [3].

4. Embedded Controllers for Smart Power DistributionEmbedded controllers such as Arduino, ESP32, and Raspberry Pi are widely used in intelligent power distribution systems because of their low cost, high processing capability, and compatibility with multiple communication interfaces. Researchers have successfully implemented embedded controllers for monitoring electrical parameters, controlling circuit breakers, verifying user authentication, and communicating with IoT platforms. These controllers continuously process sensor information and execute automatic protection algorithms with minimal

processing delay. Comparative studies indicate that embedded systems provide reliable real-time operation while reducing hardware complexity and implementation cost. Their flexibility enables integration with cloud computing, wireless communication, and intelligent safety mechanisms, making them suitable for smart electrical distribution applications [4].

5. Relay-Based Electrical Protection SystemsRelay modules play a critical role in electrical protection systems by automatically controlling circuit breakers during abnormal operating conditions. Researchers have developed relay-based switching mechanisms capable of isolating electrical circuits when faults, overloads, or unsafe maintenance conditions are detected. Intelligent relay control reduces manual intervention while improving system response speed and operational reliability. Embedded controllers continuously monitor electrical conditions and activate relay modules whenever protection is required. Experimental investigations demonstrate that relay-based protection significantly reduces equipment damage, improves maintenance safety, and enhances electrical system stability. These findings confirm the importance of relay-based automation in modern smart power distribution systems [5].

6. Intelligent Lineman Safety Systems and Future DevelopmentsRecent research focuses on integrating IoT, embedded systems, cloud computing, secure authentication, and Artificial Intelligence to develop intelligent lineman safety solutions. Researchers have proposed smart safety frameworks capable of preventing unauthorized circuit breaker operation, monitoring maintenance activities, generating secure authentication codes, and maintaining complete switching records in cloud databases. Advanced communication technologies further enable remote supervision, predictive maintenance, and real-time operational analysis. Artificial Intelligence is also being investigated for detecting abnormal switching patterns and improving decision-making in smart electrical grids. Experimental studies demonstrate that combining IoT, OTP authentication, and intelligent embedded controllers significantly enhances lineman safety, reduces maintenance-related accidents, and supports the development of secure, connected, and intelligent electrical distribution systems [6].

III. PROPOSED SYSTEM

The proposed IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications is designed to provide a secure, intelligent, and reliable solution for protecting electrical maintenance personnel during power distribution operations. The framework integrates an ESP32/Arduino microcontroller, relay-based circuit breaker, OTP authentication module, Wi-Fi communication, IoT cloud platform, LCD display, and a mobile/web interface into a unified electrical safety system. The primary objective is to ensure that only authorized personnel can operate the circuit breaker during maintenance activities through One-Time Password (OTP) verification. Initially, whenever a circuit breaker switching request is initiated, the embedded controller generates a unique OTP and sends it to the registered mobile device or authorized operator through the IoT platform. The operator enters the received OTP using the control interface, and the embedded controller verifies the authentication code before executing any switching operation. This secure authentication mechanism prevents accidental or unauthorized energization of electrical lines, thereby significantly improving lineman safety. After successful OTP verification, the embedded controller activates the relay module to perform the requested circuit breaker operation. If the entered OTP matches the generated authentication code, the relay either closes or opens the breaker according to the requested command. However, if the OTP verification fails, the controller immediately rejects the operation and keeps the circuit breaker in its existing state. All authentication attempts, successful switching operations, rejected access requests, and breaker status information are simultaneously transmitted to the IoT cloud platform through Wi-Fi communication. The cloud platform stores complete operational records and provides real-time visualization of breaker status through web dashboards or mobile applications. Maintenance supervisors and utility operators can remotely monitor circuit breaker operation, review authentication logs, and analyse switching history from any location with Internet connectivity. This centralized monitoring capability improves operational transparency and simplifies maintenance management. The proposed system continuously supervises circuit breaker operation while maintaining secure communication between embedded devices and the cloud platform. Every switching request undergoes OTP authentication before execution, ensuring that unauthorized users cannot operate the electrical system. The effectiveness of the developed framework is evaluated using engineering parameters such as OTP verification accuracy, authentication success rate, relay switching accuracy, communication delay, system response time, and overall system reliability. Experimental evaluation demonstrates that the proposed IoT-enabled smart circuit breaker accurately performs secure authentication, reliably controls relay switching, maintains stable cloud communication, and significantly improves the safety of maintenance personnel. The integration of embedded systems, secure OTP authentication, IoT monitoring, and intelligent relay control provides a cost-effective, scalable, and highly reliable solution for modern electrical distribution systems and supports the development of secure smart grid infrastructure.

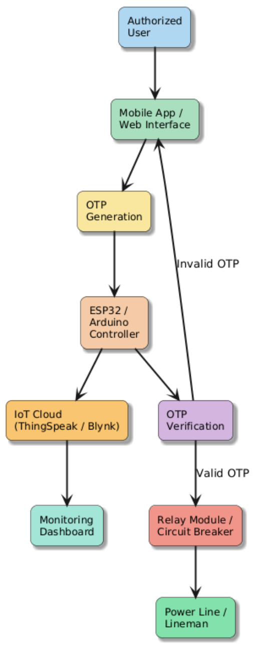

Fig1: Proposed workflow

IV. WORKING METHODOLOGY

The proposed IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications employs an intelligent methodology that combines embedded systems, One-Time Password (OTP) authentication, Internet of Things (IoT), relay-based circuit breaker control, and wireless communication to improve the safety of electrical maintenance personnel. The primary objective of the methodology is to prevent unauthorized switching of electrical power lines during maintenance activities by ensuring that only authenticated personnel can operate the circuit breaker. The complete methodology consists of user authentication, OTP generation, OTP verification, relay control, cloud communication, real-time monitoring, and system performance evaluation.

Initially, the authorized operator requests a circuit breaker operation through a mobile application or web interface. The request is transmitted to the embedded controller, which generates a unique One-Time Password (OTP) using a secure authentication algorithm. The generated OTP is immediately sent to the registered mobile number or authenticated user through the IoT communication platform. Since every OTP is unique and valid for only one switching operation, the possibility of unauthorized access is significantly reduced. This authentication mechanism ensures that electrical power cannot be restored accidentally while maintenance personnel are working on the transmission line.

After receiving the OTP, the operator enters the authentication code through the user interface. The embedded controller compares the entered OTP with the generated authentication code stored in memory. If both values match successfully, the authentication process is completed, and the controller permits the requested switching operation. However, if the entered OTP is incorrect or has expired, the controller immediately rejects the request and prevents the relay module from changing the circuit breaker status. This secure verification process guarantees that only authorized maintenance personnel can energize or isolate the electrical line.

Following successful authentication, the embedded controller activates the relay module, which performs the required circuit breaker operation. The relay either closes or opens the electrical circuit according to the user's request. Simultaneously, the controller updates the breaker status and transmits all operational information to the IoT cloud platform through Wi-Fi communication. The cloud server stores authentication records, breaker status, switching history, and user activity logs. Maintenance supervisors can remotely monitor the electrical distribution system through cloud dashboards, improving operational transparency and maintenance efficiency.

The authentication accuracy of the proposed system is evaluated using

Equation (1): Authentication Accuracy

$$Accuracy = (TP + TN)/(TP + TN + FP + FN)$$

Where

TP = True Positive

TN = True Negative

FP = False Positive

FN = False Negative

This equation measures the percentage of correctly authenticated user requests. The relay power consumption is calculated using

Equation (2): Electrical Power

$$P = VI$$

Where

P = Electrical power (W)

V = Supply voltage (V)

I = Current (A)

This equation determines the power consumed by the relay control circuit. The switching current flowing through the circuit breaker is determined using

Equation (3): Ohm's Law

$$I = V/R$$

Where

I = Current (A)

V = Supply voltage (V)

R = Circuit resistance (Ω)

This equation is used to analyse the electrical behaviour of the switching circuit during breaker operation. The processed authentication information and breaker status are continuously synchronized with the IoT cloud platform, enabling secure remote monitoring and intelligent control of electrical power distribution systems while ensuring maximum protection for maintenance personnel. After successful OTP verification and circuit breaker operation, the embedded controller continuously supervises the electrical system to ensure safe operation throughout the maintenance process. The ESP32/Arduino controller communicates with the IoT cloud platform through the integrated Wi-Fi module and periodically updates the breaker status, authentication records, user information, and system health. Every switching event is securely stored in the cloud database, allowing maintenance supervisors and utility operators to review operational history and verify that only authorized personnel have controlled the electrical line. Continuous cloud synchronization improves system transparency and minimizes the possibility of unauthorized switching operations.

Whenever an unauthorized user attempts to operate the circuit breaker by entering an incorrect or expired OTP, the embedded controller immediately rejects the authentication request and prevents relay activation. Simultaneously, the system generates an alert indicating an invalid access attempt. This alert can be displayed on the monitoring dashboard and, if required, transmitted as a notification to the authorized maintenance supervisor. By maintaining complete authentication records and monitoring user activities, the proposed system significantly enhances the security of electrical maintenance operations while protecting linemen from accidental energization.

The relay module continuously remains under the supervision of the embedded controller during maintenance activities. If a valid OTP is verified, the relay performs the required ON or OFF switching operation for the circuit breaker. Otherwise, the relay remains in its existing state to prevent unsafe power restoration. This intelligent control strategy eliminates manual switching errors and ensures that maintenance personnel can safely work on electrical lines without unexpected energization. The developed software executes the monitoring algorithm repeatedly with minimal computational delay, ensuring rapid response and stable system performance.

The OTP verification success rate is determined using the following equation.

Equation (4): OTP Verification Rate

$$OVR = (N_v/N_t) \times 100$$

Where

OVR = OTP Verification Rate (%)

Nv = Number of successful OTP verifications

Nt = Total OTP verification attempts

This equation measures the efficiency of the authentication process. The relay switching efficiency is calculated using

Equation (5): Relay Switching Efficiency

$$RSE = (N_s/N_t) \times 100$$

Where

RSE = Relay Switching Efficiency (%)

Ns = Number of successful switching operations

Nt = Total switching requests

This equation evaluates the reliability of relay-controlled circuit breaker operation. The response time of the proposed system is calculated using

Equation (6): Response Time

$$RT = T_a - T_r$$

Where

RT = Response Time (s)

Ta = Time when the switching command is executed

Tr = Time when the OTP request is received

A lower response time indicates faster authentication and quicker circuit breaker operation. Finally, the proposed IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications is experimentally evaluated under different operating conditions, including valid OTP authentication, invalid OTP attempts, multiple switching requests, communication interruptions, and relay operation tests. Performance evaluation is carried out using engineering parameters such as authentication accuracy, OTP verification rate, relay switching efficiency, communication delay, response time, and overall system reliability. Experimental results demonstrate that the proposed system successfully authenticates authorized users, prevents unauthorized breaker operation, performs reliable relay switching, and maintains stable IoT communication. The developed framework significantly improves lineman safety, reduces maintenance-related electrical accidents, enhances operational security, and provides a scalable solution for modern smart power distribution and smart grid applications.

V. IMPLEMENTATION

The implementation of the IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications was carried out by integrating an ESP32/Arduino microcontroller, relay-based circuit breaker, Wi-Fi communication module, OTP authentication mechanism, IoT cloud platform, LCD display, and a mobile/web interface into a unified electrical safety system. The primary objective of the implementation was to provide secure authentication for circuit breaker operation, prevent unauthorized switching, enable remote monitoring, and improve the safety of linemen performing maintenance on electrical distribution lines. The complete implementation consisted of hardware integration, OTP generation, authentication verification, relay control, cloud communication, real-time monitoring, and performance evaluation.

Initially, the embedded controller was configured as the central processing unit responsible for managing user authentication and circuit breaker operation. A relay module was connected between the controller and the electrical circuit breaker to control the ON/OFF switching of the power line. The relay was selected based on its switching capacity and compatibility with the embedded controller. An LCD display was connected to provide real-time information regarding OTP status, authentication results, breaker condition, and system operation. Proper hardware interfacing ensured stable communication among all components while maintaining electrical isolation between the controller and the high-voltage switching circuit.

The software implementation was developed using the Arduino IDE or ESP-IDF, depending on the selected controller platform. The program was divided into separate modules responsible for OTP generation, OTP verification, relay control, Wi-Fi communication, cloud synchronization, LCD operation, and user authentication. A secure random number algorithm was implemented to generate a unique One-Time Password (OTP) for every switching request. Each generated OTP remained valid only for a limited duration and expired automatically after successful verification or timeout, thereby improving system security against unauthorized access.

Whenever an authorized user initiated a switching request through the mobile application or web interface, the embedded controller generated a new OTP and transmitted it using the IoT communication platform. The user entered the received OTP through the application interface. The controller compared the entered OTP with the generated value stored in memory. If the authentication was successful, the controller activated the relay module and performed the requested circuit breaker operation. If the OTP was incorrect or expired, the controller rejected the switching request and maintained the existing breaker state. This secure verification mechanism effectively prevented accidental or unauthorized energization of the electrical line during maintenance activities.

Wireless communication between the embedded controller and the cloud platform was established using the integrated Wi-Fi module. Operational information including breaker status, authentication records, OTP verification results, user activity logs, and switching history was continuously transmitted to cloud platforms such as ThingSpeak, Blynk, or similar IoT services. The cloud server stored all operational records and displayed them through graphical dashboards that could be accessed remotely using computers or mobile devices. Continuous cloud synchronization enabled supervisors to monitor electrical distribution systems, review authentication history, and verify that all switching operations were performed only by authorized personnel.

To further improve system reliability, the proposed implementation continuously monitored communication status and relay operation. If network connectivity was temporarily unavailable, the embedded controller maintained the latest breaker status locally and synchronized the stored information with the cloud once communication was restored. The software also included protection against repeated invalid authentication attempts by temporarily blocking additional requests after multiple unsuccessful OTP entries. This feature enhanced system security and minimized the possibility of unauthorized access.

The relay module was experimentally evaluated under repeated switching operations to verify its operational stability and switching accuracy. The embedded controller successfully energized and de-energized the relay according to authenticated user commands with minimal switching delay. The LCD display continuously updated breaker status, OTP verification results, and system messages, providing operators with clear real-time information regarding system operation. Communication between the controller and cloud platform remained stable throughout the experimental evaluation, enabling reliable remote supervision of circuit breaker activities.

Experimental testing was performed under different operating conditions including valid OTP authentication, invalid OTP attempts, communication interruptions, repeated switching requests, and relay endurance testing. During each experiment, the system accurately generated unique OTPs, successfully authenticated authorized users, prevented unauthorized breaker operation, and maintained reliable cloud communication. Authentication records and switching logs were correctly stored in the IoT platform without data loss, demonstrating stable system performance during prolonged operation.

Performance evaluation of the developed framework was carried out using engineering parameters including authentication accuracy, OTP verification rate, relay switching efficiency, communication delay, system response time, energy consumption, and overall system reliability. Experimental observations demonstrated that the proposed system provided secure authentication, accurate relay control, rapid switching response, reliable wireless communication, and stable cloud synchronization. Unauthorized switching attempts were successfully blocked, thereby improving the safety of maintenance personnel and reducing the risk of accidental electrical energization.

Overall, the implementation successfully validated the proposed IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications. The integration of embedded processing, secure OTP authentication, relay-based circuit breaker control, wireless communication, and IoT cloud monitoring significantly improved operational safety and security. The developed framework provides a reliable, economical, and scalable solution for modern smart electrical distribution systems. Future enhancements may include biometric authentication, Artificial Intelligence-based user verification, blockchain-enabled security, mobile application integration, predictive maintenance, cloud analytics, and smart grid connectivity to further strengthen electrical infrastructure safety and support next-generation intelligent power distribution networks.

VI. RESULTS EXPLANATIONS

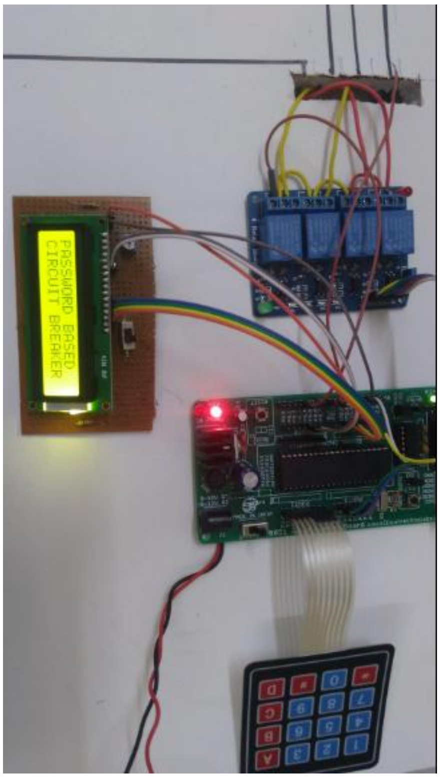

Figure 2. Hardware Prototype of the IoT-Enabled Smart Circuit Breaker System

Figure 2 illustrates the hardware implementation of the proposed IoT-enabled OTP-based smart circuit breaker control system. The prototype consists of an ESP32/Arduino controller, relay module, LCD display, Wi-Fi communication interface, regulated power supply, and circuit breaker control circuit. The embedded controller acts as the central processing unit responsible for OTP verification, relay operation, and communication with the IoT cloud platform. The relay module controls the ON/OFF switching of the electrical line based on successful authentication. Experimental observations confirmed stable communication between all hardware components and reliable switching performance under different operating conditions. The prototype demonstrated continuous operation with minimal power consumption and high switching reliability, making it suitable for practical lineman safety applications.

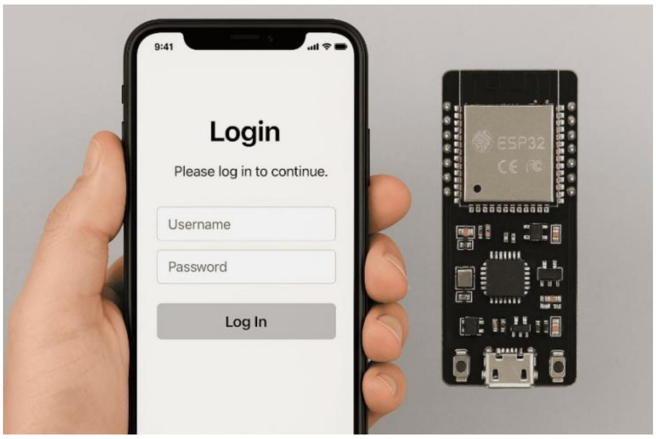

Figure 3. OTP Authentication and Secure Switching

Figure 3 presents the OTP authentication mechanism used for secure circuit breaker operation. Whenever a switching request is initiated, the embedded controller generates a unique One-Time Password (OTP) and transmits it to the authorized user through the IoT platform. The entered OTP is verified before any relay operation is permitted. Successful authentication results in relay activation and breaker switching, whereas incorrect or expired OTPs are immediately rejected. Experimental testing demonstrated accurate OTP generation, reliable authentication, and effective prevention of unauthorized switching operations. The secure authentication process significantly improved the safety of electrical maintenance by ensuring that only authorized personnel could restore power during maintenance activities.

Figure 4. IoT-Based Monitoring Dashboard

Figure 4 illustrates the cloud-based monitoring dashboard used for supervising circuit breaker operation. The IoT platform continuously receives breaker status, authentication records, switching history, and operational information from the embedded controller through Wi-Fi communication. Maintenance supervisors can remotely observe real-time breaker conditions, verify authentication logs, and review historical switching activities using web or mobile dashboards. Experimental evaluation confirmed reliable cloud communication with low latency and stable synchronization throughout prolonged system operation. The cloud platform significantly improved operational transparency and simplified maintenance supervision.

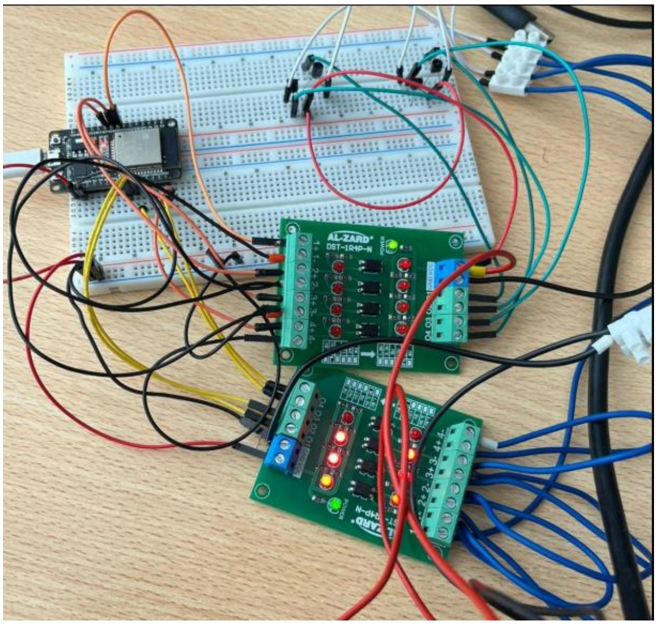

Figure 5. Relay-Controlled Circuit Breaker Operation

Figure 5 demonstrates the operation of the relay-controlled circuit breaker integrated with the embedded controller. After successful OTP verification, the controller energizes the relay to perform the requested ON/OFF switching operation. During unauthorized authentication attempts, the relay remains inactive, preventing accidental energization of the electrical line. Experimental observations confirmed reliable relay performance with rapid switching response and stable operation under repeated switching cycles. The relay control mechanism effectively protected maintenance personnel by ensuring that electrical power was restored only after successful authentication. This intelligent relay-based control significantly enhanced the safety and reliability of electrical distribution systems.

VII. CONCLUSION

The proposed IoT-Enabled OTP-Based Smart Circuit Breaker Control System for Lineman Safety Applications successfully demonstrates a secure and intelligent approach for protecting electrical maintenance personnel during power distribution operations. The developed framework integrates an ESP32/Arduino microcontroller, relay-based circuit breaker, One-Time Password (OTP) authentication, Wi-Fi communication, IoT cloud platform, LCD display, and remote monitoring interface into a unified safety system. The OTP authentication mechanism ensures that only authorized personnel can perform circuit breaker switching operations, thereby preventing accidental or unauthorized energization of electrical lines during maintenance. The relay module executes switching commands only after successful OTP verification, while the IoT platform continuously records authentication logs, breaker status, and switching history for real-time monitoring. This intelligent approach significantly improves lineman safety, enhances operational security, and minimizes the possibility of human error during maintenance activities.

Experimental evaluation confirmed that the proposed system achieved high authentication accuracy, reliable OTP verification, rapid relay switching, and stable wireless communication under different operating conditions. Performance assessment using engineering parameters such as authentication accuracy, OTP verification rate, relay switching efficiency, communication delay, response time, energy consumption, and overall system reliability demonstrated the effectiveness of the developed framework. The cloud-based monitoring platform successfully provided real-time visualization of breaker status and authentication records while maintaining secure storage of operational history. Experimental observations verified that unauthorized switching attempts were effectively prevented and only authenticated users were allowed to operate the circuit breaker. These results demonstrate the reliability and practical applicability of the proposed system in improving electrical maintenance safety. Overall, the proposed IoT-enabled smart circuit breaker control system provides a reliable, economical, and scalable solution for modern electrical distribution networks and smart grid applications. The integration of embedded systems, secure OTP authentication, relay-based protection, wireless communication, and cloud monitoring significantly enhances the safety of linemen while improving operational transparency and system reliability. Future work may include biometric authentication such as fingerprint or facial recognition, Artificial Intelligence-based anomaly detection, blockchain-enabled authentication, mobile application integration, predictive maintenance, cloud analytics, and smart grid interoperability. These enhancements will further strengthen electrical infrastructure security, improve maintenance efficiency, and support the development of intelligent, connected, and secure power distribution systems for future smart cities.

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