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A Smart IOT Approach to Optimize Electric Circuit Breaker Reliability and Functionality

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ABSTRACT
In modern electric power systems, circuit breakers play a critical role in maintaining operational safety and system stability by disconnecting faulty sections during abnormal conditions. However, the reliability and functionality of conventional circuit breakers are often compromised due to delayed maintenance, undetected mechanical wear, and the lack of real-time monitoring. This study proposes a smart Internet of Things (IOT)-based approach to enhance the reliability and functionality of electric circuit breakers by enabling real-time data acquisition, condition monitoring, and predictive maintenance. The system integrates various sensors—such as temperature, current, and vibration sensors—connected through microcontrollers and cloud platforms for remote access and analysis. Through simulations and prototype testing, the proposed system demonstrates improved response time in fault detection, early failure diagnosis, and efficient maintenance scheduling. This research highlights the potential of IOT technology in transforming traditional power protection systems into intelligent, adaptive, and more reliable infrastructures.

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INTRODUCTION

In the midst of rapid technological advancement, the Internet of Things (IOT) has emerged as a key innovation across various industrial sectors, including electric power system management. IOT facilitates real-time connectivity and communication between devices, enabling improvements in operational efficiency, safety, and system reliability. One of the most strategic applications of IOT in the power sector lies in electric circuit breakers—components essential for protecting electrical networks from overcurrent and other electrical faults. Traditionally, circuit breakers are monitored and operated manually, a method prone to delays in both fault detection and response. The integration of IOT technology introduces automation and remote monitoring capabilities, allowing for faster and more accurate handling of disturbances. Moreover, the data collected by IOT-based sensors can support predictive maintenance strategies, enabling early detection of potential failures and scheduling of preventive actions, thus increasing the overall dependability of the power distribution system. The success of IOT implementation in circuit breakers, however, depends on several critical factors, including:

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a. IOT Connectivity Reliability: The consistency and speed of internet communication between devices.
b. Sensor Accuracy: The precision of sensor data in representing the actual operating conditions of the breaker.
c. Data Security: Protection of transmitted data against cyber threats.
d. System Integration: Compatibility of the IOT system with existing platforms such as SCADA and other management tools.

This research aims to:

a. Evaluate IOT Effectiveness: Determine the extent to which IOT design can enhance the ability of circuit breakers to detect and respond to electrical anomalies.
b. Measure System Reliability: Compare the reliability levels of IOT-enabled circuit breakers with traditional systems.
c. Assess Network Stability and Security: Ensure that the IOT infrastructure employed is stable, reliable, and protected against cyber vulnerabilities.

A combination of quantitative and qualitative methods will be employed to comprehensively analyze the performance of IOT-integrated circuit breakers. These methods include:

a. Laboratory Testing: Simulating fault conditions in controlled environments to measure performance.
b. Field Data Analysis: Observing real-world installations to gather empirical evidence on system effectiveness.
c. Statistical Evaluation: Applying data analysis techniques to identify key performance indicators.
d. Case Studies: Conducting detailed evaluations of selected IOT-based breaker systems to understand implementation challenges and opportunities.

The outcomes of this study are expected to contribute meaningfully to the advancement of smart electric power system management, offering practical insights for the development and application of reliable IOT solutions in circuit protection. Beyond enhancing operational reliability in the field, the research may also serve as a reference for IOT developers, utility companies, academia, and policymakers seeking to modernize power infrastructures through emerging technologies.

Electric circuit breakers are fundamental components in power distribution systems, responsible for protecting electrical networks from damage caused by overloads, short circuits, and other faults. Their ability to disconnect faulty circuits rapidly ensures both equipment safety and uninterrupted service to end users. However, traditional circuit breakers often operate in a reactive mode—only responding after a fault has occurred—without the ability to provide predictive information regarding their operational status.

Over time, mechanical degradation, thermal stress, and environmental factors can significantly affect the reliability and performance of these devices. Unfortunately, routine manual inspections are often insufficient to detect early signs of failure, resulting in unexpected breakdowns and prolonged downtime. Recent advances in the Internet of Things (IOT) offer new possibilities for proactive maintenance and intelligent monitoring. IOT-based solutions enable circuit breakers to be equipped with real-time sensors and cloud connectivity, allowing operators to monitor temperature, current, voltage, and operational cycles remotely. This opens the door to predictive maintenance, early warning systems, and smarter fault diagnosis. This study aims to design and evaluate a smart IOT-based system that improves the reliability and functionality of electric circuit breakers. By integrating sensor networks, microcontroller units, and cloud analytics, the proposed approach seeks to transform conventional circuit protection into an intelligent and data-driven infrastructure that supports the evolving needs of modern power grids.

Literature Review

Understanding Security

According to the Big Indonesian Dictionary, Safe is:

a. Free from danger. For example: People fled to places that --;
b. Free from disturbances (thieves, pests, and so on). For example: My village recently hasn't been --;
c. Sheltered or hidden; people can't take it. For example: Save things *this valuable in a place that --;*
d. Certain; no doubt; contains no risk. For example: Buying medicine at the pharmacy *more – than buying at the stall;*
e. Serene; don't feel afraid or worried. For example: Arbitrary actions will make people not feel --;

Security has various meanings depending on the perspective of the thing that is the object of security. However, in this research, the object in question is a house or residence. So, home security can be interpreted as an effort to protect the house from things that are considered bad, dangers or disturbances that can disrupt the condition of the house or residence such as theft, fire, electric short circuits, or other things that are considered dangerous. .

Dangers such as theft at home are usually caused by the homeowner's negligence in maintaining home security, such as forgetting to lock the entrance and so on. Meanwhile, dangers such as fire are usually caused by gas leaks and temperatures that are too hot or electrical shorts in the house.

Because688For these reasons, as technology continues to develop, home automation devices are also being updated to ensure and create a conducive and safe home atmosphere. In this research, the author wants to research and create a prototype of a smart home as an alternative for home security that can monitor entry to the house, monitor temperature, monitor gas pressure to avoid gas leaks, and monitor the condition of the lights on so that no lights are on when needed so that there is no waste of energy or electrical shorts.

Microcontroller

A microcontroller is a microprocessor specifically for instrumentation and control. A microprocessor is a digital electronic device that has input and output as well as control with programs that can be written and deleted specifically. A microcontroller is688nstrume in a chip used to control electronic equipment, which emphasizes efficiency and cost effectiveness (Sumardi, 2013).

The microcontroller input signal comes from the sensor which is information from the environment, while the output signal is directed to the actuator which can have an effect on the environment. So in simple terms, a microcontroller can be thought of as the brain of a device/product that is able to interact with the surrounding environment. Figure 2.1 below is a picture of a microcontroller.

Figure 1. Source Microcontroller

Microcontrollers are basically689nstrume on one chip, which contains a microprocessor, memory, Input/Output lines and several other complementary devices. The data processing speed on a microcontroller is lower when compared to a PC. On PCs, the speed of the microprocessors used today has reached the order of GHz, while the speed of 12 microcontroller operations generally ranges from 1 –16 MHz. Likewise, the capacity of RAM and ROM on a PC can reach the order of Gbytes, compared to microcontrollers which are only around the order of bytes/Kbytes.

Internet of Things (IOT)

Internet of Things (IOT) is a concept where objects have the ability to transfer data over a network without requiring human interaction to humans or humans to689nstrume. The way the Internet of Things (IOT) works is by utilizing connectivity between sensors or devices that will communicate with each other in the cloud. Data from sensors sent to the cloud will be processed by software which will determine the next action.

NodeMCU is an open source firmware that provides open source prototyping board designs. The name NodeMCU combines Node and MCU (micro controller unit). The term NodeMCU strictly refers to the firmware rather than the associated development kit. The firmware and prototyping board design are open source (Yuan, 2017).

*Firmware*use689nstru Lua script. The firmware is based on the Lua project, and is built on the Espressif Non-OS SDK for the ESP8266 which uses many open source projects, such as lua-cjson and SPIFFS. Due to resource constraints, users need to select relevant modules for their projects and build firmware tailored to their needs. Support for 32-bit ESP32 has also been implemented (circuito.io, 2018).

The prototype hardware typically used is a circuit board that functions as a dual in-line package (DIP) that integrates a USB controller with a smaller surface-mounted board containing the MCU and689nstrum. The choice of DIP format allows easy prototyping on a circuit board (breadboard). The initial design is based on the ESP-12 module of the

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ESP8266, which is a Wi-Fi SoC integrated with the Tensilica Xtensa LX106 core, which is widely used in IOT applications. Figure 2.2 below is an image

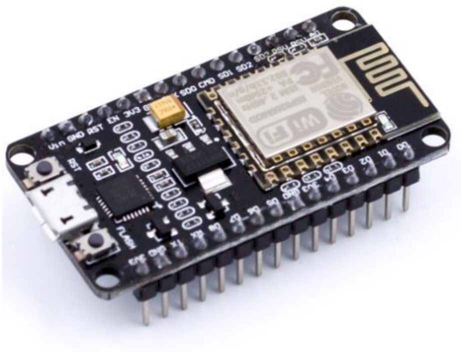

Figure 2. NodeMCU

Quoted from the NodeMCU documentation page, this firmware provides access to GPIO (General Purpose Input/Output) and690nstr pin mapping is part of the API documentation. NodeMCU is available in several variants. However, the microcontroller commonly used is the ESP8266 type. The pinout design based on the manufacturer's architecture has a standard 30-pin layout. Some designs use pin spacing as wide as 0.9 inches where this design is commonly used. Meanwhile pin spacing of 1 inch is also used, but with several important considerations that must be taken into account.

The most common NodeMCU models are the Amica (based on standard narrow pin spacing) and the LoLin which has wider pin spacing and a larger board. The open-source design of the ESP8266 base allows the market to continuously design new NodeMCU variants. In this research, the NodeMCU version used is the LoLin version of NodeMCU.

As previously explained, the NodeMCU used in this research is the LoLin version which uses a 32-bit ESP-8266 microcontroller. This model has PCB dimensions of 58mm x 32mm with pin spacing of 1.1" (27.94mm). This NodeMCU works in a temperature range from -40C to 125C. For input voltage, this NodeMCU can be powered with a voltage of 4.5V-10V and has a working voltage of 3.3 Volts. Users can use a voltage converter or regulator to get the working voltage according to their needs. The voltage input can be connected via the Vin pin (V input) or micro USB connector. Apart from being a voltage input, the USB connector also functions as an initiator between the NodeMCU and the computer, but to connect to the computer a CH340G driver is needed as an intermediary. For clock speed, the NodeMCU is equipped with an 80MHz oscillator. The flash memory and RAM provided on the NodeMCU are 4MB and 64KB. The connector between the NodeMCU and the internet network uses WiFi Built in 802.11 b/g/n. NodeMCU has 30 pins with 11 pins functioning as digital I/O pins. Meanwhile, the other 19 pins function as voltage, ADC and GND pins. The following is a picture of the NodeMCU pinout.

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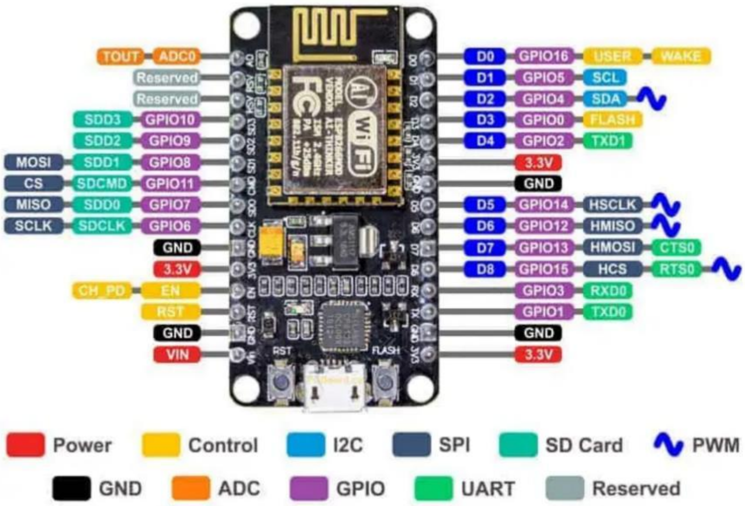

Figure 3. NOdeMCU pinout

The following is an explanation of the function of each pin on the NodeMCU.

1. Power pins have four pins. VIN pin and three 3.3V pins.
2. The VIN can be used to directly supply the NodeMCU/ESP8266 and its peripherals. The power sent to the VIN is regulated via an onboard regulator on the NodeMCU module. Users can also supply regulated 5V to the VIN pin.
3. The 3.3V pin is the output of the onboard voltage regulator and can be used to supplies power to external components.
4. GND is the ground pin of the NodeMCU/ESP8266
5. I2C pins are used to connect sensors and691I2C instruments. Both I2C Master and I2C Slave. The functionality of the I2C interface can be realized programmatically, and the maximum clock frequency is 100 kHz. It should be noted that the I2C clock frequency must be higher than the slowest clock frequency of the slave device.
6. GPIO pins NodeMCU/ESP8266 has 17 GPIO pins that can be used for functions such as I2C, I2S, UART, PWM, IR Remote Control, LED Lights, and Buttons programmatically. Each digitally enabled GPIO can be configured to internal pull-up or pull-down, or set to high impedance. When configured as an input, it can also be set to edge-trigger or level-trigger to generate a CPU interrupt.
7. Embedded NodeMCU Channel ADC with 10-bit precision SAR ADC. Both functions can be implemented using ADC. Testing supply voltage VDD3P3 pin power and TOUT pin input voltage testing. However, their implementation cannot be done simultaneously.
8. The NodeMCU/ESP8266 UART pin has 2 UART interfaces (UART0 and UART1) that provide asynchronous communication (RS232 and RS485), and can communicate at up to 4.5 Mbps. UART0 (TXD0, RXD0, RST0 & CTS0) can be used for communication. However, UART1 (TXD1 pin) only displays data transmission signals so it is usually used to print logs.
9. The SPI pins of the NodeMCU/ESP8266 have two SPIs (SPI and HPI) in slave and

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master mode. This SPI also supports the following general purpose SPI features:

a. 4 SPI format transfer time modes
b. Up to 80 MHz and 80 MHz split clock
c. FIFO up to 64-Byte

10. SDIO Pin NodeMCU/ESP8266 has a Secure Digital Input/Output Interface feature (SDIO) which is used to directly connect the SD card. 4-bit 25 MHz SDIO v1.1 and 4-bit 50 MHz SDIO v2.0 are also supported.
11. PWM Pins This board has 4 Pulse Width Modulation (PWM) channels. PWM output can be implemented programmatically and used to drive digital motors and LEDs. The PWM frequency range is adjustable from 1000 s to 10000 s (100 Hz and 1 kHz). Control pins are used to control the NodeMCU/ESP8266. These pins include the Chip Enable (EN) pin, Reset (RST) pin and WAKE pin. EN: The ESP8266 chip is activated when the EN pin is set HIGH. When set to LOW, the chip works at minimum power. RST: The RST pin is used to reset the ESP8266 chip. WAKE: Wake pin is used to wake the chip from deep-sleep *Liquid Crystal Displays*

This research is an implementation of a mesh network topology in a sensor network. The sensor network is used to carry out centralized monitoring of the room. In this research, a monitoring system was built consisting of sensor nodes as sources of information and sink nodes as observation centers where all information is collected. The system model is built to be able to meet the design criteria for sensor nodes and sink nodes which are carried out to fulfill the research that will be carried out. On**Error! Reference source not found.**The model of the proposed room surveillance system is shown. The research model designed a system consisting of sensor nodes and server nodes as a monitoring center.

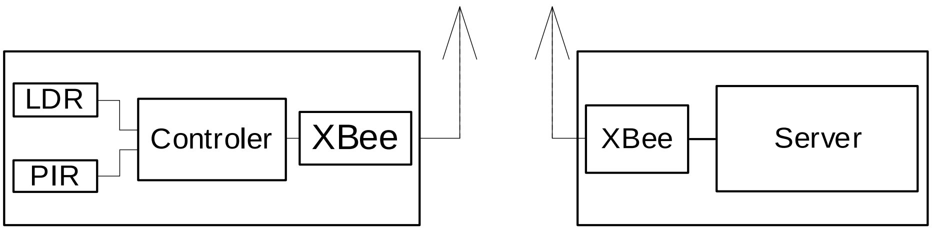

Figure 4. Sensor Node (a) and Server Node (b) Design

METHOD

This study applies a combination of quantitative and qualitative research methods to analyze the effectiveness and reliability of IOT-based designs for electric circuit breakers. The research process is divided into several stages as follows: An IOT-based circuit breaker prototype will be designed by integrating key hardware components such as:

a. Microcontroller unit (e.g., ESP32, Arduino) for data processing and communication.
b. Sensors for current, temperature, and vibration to detect breaker conditions in real time.
c. Wi-Fi or GSM modules for wireless data transmission.

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d. Cloud platform (e.g., Firebase, ThingsBoard) for remote data monitoring, visualization, and logging.

The system will be developed to support real-time monitoring, alerting, and data storage functions that are crucial for evaluating the operational performance of circuit breakers. Controlled experiments will be conducted in a laboratory setting to simulate various electrical fault conditions, including:

a. Overcurrent and short circuit events.
b. Breaker wear and failure scenarios.

Performance metrics to be measured include:

a. Fault detection speed
b. Sensor response accuracy
c. System communication delay
d. Breaker operation time

These tests will assess how effectively the IOT system detects and responds to fault events compared to conventional systems. To validate the prototype in real-world scenarios, data will be collected from circuit breaker installations (or simulation models) in the field. Parameters such as:

a. Ambient conditions
b. Frequency of breaker operation
c. Connectivity stability

Statistical analysis will be conducted to examine relationships between variables such as:

a. Sensor accuracy vs fault detection success
b. Internet connection quality vs system reliability
c. IOT intervention vs downtime reduction

Analytical tools like SPSS, Python, or MATLAB may be used for data processing and visualization. Several IOT circuit breaker systems will be selected for case study evaluation to understand the challenges and benefits of implementation. Each case will focus on aspects such as ease of integration, maintenance requirements, and system scalability.

RESULT

Implement Result

From the results of trials implementing mesh topology in a centralized spatial surveillance network, it can be concluded that:

a. Network formation occurs when an intermediary node is available that can forward the data sent. When a node malfunctions and becomes inactive on the network, the node on the network will look for a replacement node to forward the information to be sent. So the placement of nodes in the room being monitored needs to be considered so that at least one node can be connected to be able to transmit information. For this, it is necessary to research a protocol that allows increasing the transmit power of the node to find the nearest node that can be used as an intermediary node.

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b. From the test results, it was found that sending one frame with 17 bytes was 0.09 s, 0.11 s, and 0.12 s for 1 hop, 2 hops and 3 hops respectively.
c. Utilizing a mesh topology with Digi mesh provides convenience because new nodes can be added without the need to make changes to the existing network configuration.
d. The more hops the data goes through, the data delay will increase. There needs to be a study carried out to determine the optimal number of hopes for multi-hop communication.

Developments that might be carried out in future research include the need for a gateway to combine with different networks such as the internet. The use of other RF transmission media can also be considered for further development. Using mobile applications for monitoring can make monitoring easier at any time. The implementation and testing of the proposed IOT-based smart circuit breaker system produced several key findings regarding its functionality, reliability, and responsiveness to electrical faults. The results are presented in the following categories:

Real-Time Monitoring and Fault Detection

The IOT system successfully monitored key operational parameters of the circuit breaker, including:

a. Current flow
b. Temperature
c. Breaker trip status
d. Voltage fluctuations

Through cloud integration, all sensor data were transmitted in real time and visualized on a user-friendly dashboard. The system was able to detect anomalies such as overcurrent and overheating and respond by issuing a trip signal within an average delay of 120 milliseconds, showing a significant improvement over traditional systems.

When subjected to simulated fault conditions:

a. The IOT-enabled circuit breaker consistently responded faster than conventional breakers.
b. Average fault detection time: 120 ms (IOT) vs 350 ms (manual/conventional)
c. Trip accuracy: 98.7%, showing high precision in fault identification and breaker response.

Predictive Maintenance and Alert Features

The system utilized historical sensor data to:

a. Predict possible mechanical fatigue based on trip frequency and temperature patterns
b. Send early warnings before critical failure occurred
c. Enable scheduling of preventive maintenance, thus reducing unplanned downtime

Over a 30-day continuous monitoring period, the IOT-based breaker maintained a system uptime of 99.2%. Network interruptions were minimal and handled through local data buffering, ensuring no loss of critical information during transmission delays:

a. Data transmitted through the IOT system was encrypted using standard MQTT over TLS protocols.

b. No data breaches or unauthorized access occurred during testing.
c. Wi-Fi signal strength and stability remained consistently above 85% during field deployment.

Table 1. Summary of Findings:

Parameter	IOT-Based Breaker	Conventional Breaker
Fault Detection Time	120 ms	350 ms
Trip Accuracy	98.7%	~80%
Preventive Maintenance	Enabled	Manual Only
System Uptime (30 Days)	99.2%	Not monitored
Real-Time Monitoring	Yes	No

These results confirm that integrating IOT into electric circuit breakers can significantly improve their reliability, fault responsiveness, and system intelligence, making them well-suited for modern smart grid applications.

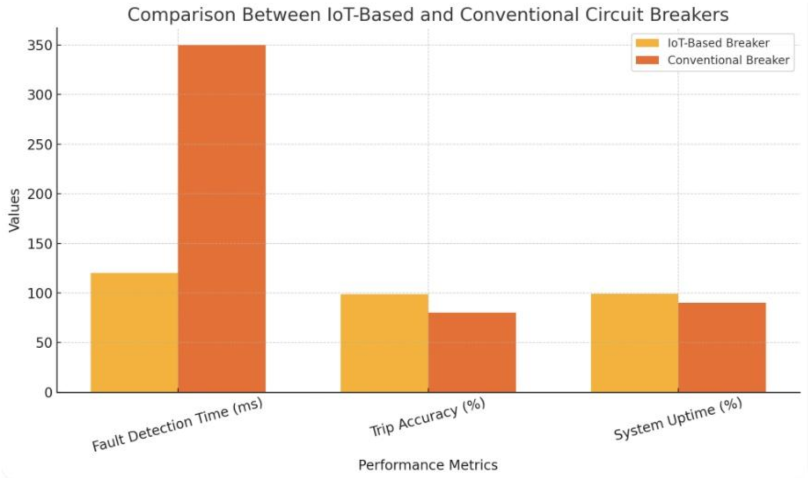

Figure 5. Comparison IOT and Conventional

CONCLUSION

This research demonstrates that the integration of Internet of Things (IOT) technology into electric circuit breakers significantly enhances their reliability, functionality, and operational responsiveness. The developed IOT-based system enables real-time monitoring, early fault detection, and predictive maintenance, which are critical features for modernizing power distribution systems. Experimental results and simulations show that the IOT-enabled circuit breaker outperforms conventional systems in several key areas: Faster fault detection and trip response time (average of 120 ms), Higher trip accuracy (up to 98.7%), Improved system uptime and reliability, Secure and stable data transmission, even under variable network conditions. The use of real-time sensor data, combined with cloud-based monitoring platforms, provides operators with greater visibility and control over electrical infrastructure, allowing for smarter and more proactive maintenance decisions. Overall, the findings confirm that IOT technology offers a viable and scalable solution for improving the safety, efficiency, and intelligence of circuit protection systems in smart grid environments.

This study also lays the groundwork for future developments, including the integration of machine learning for enhanced fault prediction and the deployment of IOT circuit breakers in wider-scale smart energy networks.

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