

Design and Implementation of an Electrical Safety Monitoring System in Electrical Engineering and Automation

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Abstract: With the rapid development of electrical engineering and automation technologies, the importance of electrical safety monitoring systems has become increasingly prominent. This paper addresses common safety hazards in electrical engineering and, combined with cutting-edge technologies such as the Internet of Things (IoT), big data, and artificial intelligence (AI), designs an intelligent electrical safety monitoring system. The paper elaborates on the overall system architecture, hardware design, and software design, including precise sensor selection and placement, data acquisition and preprocessing algorithms, big data analysis model construction, and intelligent early-warning strategy formulation.

Keywords: Electrical engineering; automation; electrical safety monitoring system; real-time monitoring; intelligent early warning

Introduction

The widespread application of electrical engineering and automation technologies has greatly promoted social productivity, but it has also introduced numerous safety hazards. Issues such as equipment overload, overheating, short circuits, and poor line contacts frequently cause electrical fires, posing serious threats to human life and property. Traditional electrical safety monitoring methods primarily rely on manual inspection and periodic maintenance, which are inefficient and often respond too slowly to incidents, making it difficult to meet the high safety requirements of modern electrical systems.

Therefore, designing an intelligent and real-time electrical safety monitoring system is of significant practical importance.

1. Requirement Analysis of the Electrical Safety Monitoring System

1.1 Analysis of Electrical Safety Hazards

The safety hazards in electrical engineering can be classified into two main categories. The first category is equipment-related faults, including overload, overheating, short circuits, insulation damage, and other malfunctions of electrical equipment. The second category is external environmental factors, such as the presence of flammable materials or inadequate



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management practices. Among these, equipment faults are the primary cause of electrical fires. Statistics indicate that electrical fires account for more than 30% of all fire incidents, and this proportion is increasing annually. Therefore, the design of an electrical safety monitoring system should focus on monitoring the operational status of electrical equipment and providing early warnings of potential faults.

1.2 Functional Requirements of the System

The electrical safety monitoring system should include the following core functions: (1) Real-time Monitoring: The system should be capable of continuously collecting operational parameters of electrical equipment, such as voltage, current, temperature, and power factor, ensuring data accuracy and timeliness; (2) Data Analysis: The collected data should be analyzed rapidly and accurately to identify abnormal operating conditions of electrical equipment, providing a basis for fault prediction and early warning; (3) Intelligent Early Warning: Based on data analysis, the system should generate alerts for potential electrical safety hazards, prompting relevant personnel to take timely measures and prevent accidents^[1]; (4) Remote Management: The system should support remote monitoring of electrical equipment status through mobile apps or computer terminals, facilitating convenient remote control and management; (5) Historical Data Management: The system should store historical data, support data retrieval and report generation, and provide a reliable data foundation for maintenance and management of electrical equipment.

2. Overall Architecture Design of the Electrical Safety Monitoring System

2.1 System Architecture Overview

The electrical safety monitoring system adopts a layered and distributed architecture, consisting of four layers: the Perception Layer, Network Layer, Platform Layer, and Application Layer. The Perception Layer is responsible for collecting operational parameters of electrical equipment; the Network Layer handles data transmission and communication; the Platform Layer manages data storage, processing, and analysis; and the Application Layer provides the user interface and intelligent early-warning functions.

2.2 Perception Layer

The Perception Layer serves as the front-end of

the electrical safety monitoring system, mainly composed of various sensors and on-site monitoring devices. Sensors are responsible for collecting operational parameters of electrical equipment, such as temperature, current, and voltage. On-site monitors use high-performance microcontrollers (MCUs) as the core processors, responsible for preliminary data processing and transmission. A dual-MCU architecture is adopted to improve system reliability and stability.

2.3 Network Layer

The Network Layer transmits the data collected by the Perception Layer to the Platform Layer. Depending on the application scenario, either wired or wireless communication can be used^[2]. Wired communication, such as Ethernet or RS485, offers high transmission speed and stability. Wireless communication, such as Wi-Fi, ZigBee, or LoRa, provides convenient installation and high flexibility. In practice, the appropriate communication method should be selected based on the distribution of electrical equipment and communication requirements.

2.4 Platform Layer

The Platform Layer is the core of the electrical safety monitoring system, mainly responsible for data storage, processing, and analysis. It employs cloud computing technology to store data on cloud servers, enabling centralized management and sharing. Additionally, big data analytics are applied to perform in-depth mining and analysis of collected data, identifying abnormal operating conditions and potential safety hazards in electrical equipment.

2.5 Application Layer

The Application Layer constitutes the user interface of the electrical safety monitoring system, primarily providing user interaction and intelligent early-warning functions. It adopts a graphical interface design to facilitate monitoring of electrical equipment status and historical data. Furthermore, it supports intelligent early warning, automatically generating alerts based on data analysis results and notifying relevant personnel via SMS, email, or other channels to ensure timely response.

3. Hardware Design and Implementation of the Electrical Safety Monitoring System

3.1 Accurate Selection and Layout of Sensors

Temperature Sensors: For transformer equipment,

high-precision PT100 platinum resistance temperature sensors are selected, with a measurement range of $-50\text{ }^{\circ}\text{C}$ to $200\text{ }^{\circ}\text{C}$ and an accuracy of $\pm 0.1\text{ }^{\circ}\text{C}$, enabling precise monitoring of transformer oil temperature variations. The sensors are installed at the top of the transformer oil tank and fixed with thermal conductive adhesive to ensure full contact with the oil temperature. For motor equipment, K-type thermocouple temperature sensors are adopted due to their wide measurement range, suitable for monitoring different parts of the motor, and are placed near the stator windings.

Current Sensors: Hall-effect current sensors are used, offering good linearity, fast response, and excellent isolation performance. The rated current of the equipment determines the sensor range. For example, for devices rated at 100 A, a current sensor with a 0-150 A range is selected. The sensor is connected in series within the circuit to ensure accurate current measurement.

Voltage Sensors: A resistive voltage divider type sensor is employed for its simple structure and low cost. Based on the rated voltage of the equipment, appropriate divider resistors are designed to convert high voltages into low-voltage signals suitable for MCU acquisition^[3]. The voltage sensor is connected in parallel to the equipment circuit terminals to achieve accurate voltage measurement.

3.2 On-site Monitoring Unit Design

Core Processor Selection: The STM32F407ZGT6 is selected as the core processor of the monitoring unit. This MCU, based on the ARM Cortex-M4 core, operates at up to 168 MHz and provides rich peripheral resources such as ADC, UART, SPI, and I²C, which meet the requirements of data acquisition, processing, and communication.

Data Acquisition Circuit Design: The MCU's built-in ADC module is used to acquire sensor signals. Analog voltage signals from temperature sensors are converted into digital signals through ADC. To improve accuracy, a 12-bit ADC with a resolution of 1/4096 is employed. An RC filter circuit is added to the ADC input to eliminate high-frequency noise.

Communication Interface Design: The communication interface depends on the selected method. For Ethernet communication, the W5500 controller chip is adopted, which integrates a TCP/IP protocol stack and enables

efficient Ethernet communication. Data are transferred to the network layer via the SPI interface with the MCU. For RS485 communication, the MAX485 chip serves as the transceiver, enabling serial communication between the MCU and the host computer.

Power Supply Circuit Design: A stable power circuit is designed for the monitoring unit. A switching power module converts AC mains to a 5 V DC supply, which is then regulated to 3.3 V using a linear regulator such as AMS1117-3.3 to power the MCU and peripheral chips. Filter capacitors and protection diodes are added to enhance power stability and anti-interference capability.

3.3 Communication Module Design

Wired Communication Module: For Ethernet communication, the W5500 Ethernet module is used, integrating both physical and MAC layers, and supporting 10/100 Mbps transmission rates. Data are transmitted via an RJ45 interface connected to a network switch or router. During hardware design, impedance matching and electromagnetic compatibility (EMC) considerations are required to ensure stable communication.

Wireless Communication Module: For Wi-Fi communication, the ESP8266 module is adopted, which integrates the Wi-Fi protocol stack and supports STA/AP mode switching, facilitating seamless connection to Wi-Fi networks. Data are transferred to the cloud server via the UART interface with the MCU. In terms of layout, the wireless module should be placed away from interference sources such as motors and transformers to improve communication quality.

4. Software Design and Implementation of the Electrical Safety Monitoring System

4.1 Data Acquisition and Processing Software Design

Data Acquisition Program: Real-time data acquisition is achieved using interrupt-driven mechanisms. A timer interrupt is configured in the MCU to periodically trigger ADC sampling interrupts. In the ADC interrupt service routine, the conversion results are read and stored in a buffer. To enhance real-time performance, a double-buffering technique is applied. Two data buffers are used alternately: while one buffer is being read, the other continues data acquisition, thus avoiding data loss.

Data Preprocessing Algorithm: Raw data are preprocessed to remove noise and interference. A

moving average filtering algorithm is employed for parameters such as temperature and current. This algorithm effectively smooths the data and reduces random noise. The mathematical expression of the moving average is:

$$y(n) = \frac{1}{N} \sum_{i=0}^{N-1} x(n-i)$$

where $y(n)$ is the filtered output, $x(n)$ is the input signal, and N is the window size. Typically, N is selected between 5 and 10, depending on application requirements.

4.2 Data Analysis and Early Warning Software Design

Big Data Analysis Model Construction: A machine learning-based approach is adopted to construct normal operation models of electrical equipment. Large-scale historical data, including parameters such as temperature, current, and voltage under normal operating conditions, are collected, preprocessed, and used for feature extraction. A Support Vector Machine (SVM) algorithm is then applied to train the model. The SVM identifies an optimal hyperplane in high-dimensional space to distinguish between normal and abnormal states^[4]. The trained model is used to classify real-time data and determine whether the equipment is operating normally.

Intelligent Early Warning Strategy: Intelligent multi-level warning mechanisms are developed based on the analysis results. When real-time data exceed the primary threshold, an initial warning is generated to alert personnel. When data exceed the secondary threshold, a high-level warning is issued, triggering emergency measures such as cutting off the power supply. Furthermore, thresholds are dynamically adjusted according to the type of equipment and operating environment, thereby improving both the accuracy and timeliness of the warning system.

4.3 User Interface Software Design

Graphical Interface Design: The Qt framework is used to design the graphical user interface (GUI). Qt is a cross-platform C++ application development framework that provides abundant widgets and strong scalability. A user-friendly interface is created to present equipment status in charts and graphs. For instance, line charts display temperature trends, while bar charts visualize current and voltage magnitudes.

Data Query and Report Generation: The user interface supports data query functions, allowing users to retrieve historical data by time, device name, or other criteria. Additionally, report generation is implemented, enabling the export of query results into Excel spreadsheets for management and analysis. Reports include parameters such as device name, timestamp, temperature, current, and voltage.

Conclusion

This paper presents the design of an intelligent electrical safety monitoring system based on IoT, big data, and AI technologies. The overall system architecture, hardware design, software implementation, and key technologies are elaborated in detail, demonstrating its effectiveness and practicality. Looking forward, the system will be further enhanced with more advanced sensor technologies to improve data accuracy and reliability, as well as more intelligent algorithms to refine data analysis and enhance real-time warning capabilities. Moreover, issues such as system security, stability, and scalability must be continuously addressed. These efforts will ensure improved performance and user experience, ultimately contributing to the safe development of electrical engineering and automation.

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