A Design of Monitoring System for Low-Voltage Distribution Station

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Abstract. In order to improve the low-voltage distribution station’s stability and safety, a monitoring system for this station based on the STM32 microprocessor is designed. The system can collect data on the environmental and switch status of multiple power distribution stations in the partial area through NB-loT Technology, then report it to the cloud platform server in the form of CoAP protocol with XTEA encryption algorithm. The cloud platform server transmits the data to the monitoring platform, categorizes and stores the node data. After on-site installation and deployment, the self-designed plug device can reduce the complexity of the plug-in. The system possesses the characteristics of instantaneity, automatic networking and high security, which can meet the industrial requirements well.

1. Introduction

The Low-voltage distribution station plays a vital role in the power system. Due to its large scale and numerous distribution, the loop lines, gate switches and internal environment of distribution stations cannot be often monitored and overhauled effectively [1]. In addition, a large amount of heat energy will be generated because of the year-round operation which often causes damage to the component, so the electrical characteristics cannot be guaranteed. Due to regional differences, the year-round high temperature will easily lead to the phenomenon of thermal expansion and softening of the lines in the station. Most low-voltage power distribution stations have not been renovated for cities and towns, and users introduce power supply directly on the branch lines generally. This behavior of connecting wires privately can lead to the entanglement and intricate branch lines in the station, which will bring hidden safety trouble and make operation and maintenance work very difficult [2].

This article designs a monitoring system for low-voltage distribution stations, which uses Embedded Microprocessing Technology to develop a data collection system with high reliability and low power consumption. It then effectively solves the problem of safety hazards in distribution stations based on NB-loT technology and large-scale multi-point data collection.

2. System design architecture

A complete monitoring system for low-voltage distribution stations consists of the following four parts: front-end detection, IoT communication network, cloud platform server, and user terminal. The system architecture diagram is shown in Figure 1.
The front-end detection captures the data information in the distribution station and allocates the operation mode of each module mainly under the responsibility of the STM32 microprocessor. IoT communication network consists of NB-IoT terminals, wireless networks and core networks, responsible for establishing transmission channels for NB-IoT terminals to transmit upstream and downstream data services. The cloud platform server can receive the requested content obtained from the core network and enable the device to access the Internet. The user terminal is in charge of monitoring system status and managing background data.

3. Hardware design of the system

The system’s hardware is mainly composed of STM32F407 microprocessor, switch monitoring unit, environmental monitoring unit, NB-IoT communication module, and plug device. The hardware block diagram of the system is shown in Figure 2.

3.1 STM32 microprocessor selection

The microprocessor used in front-end detection is STM32F407, an ARM Cortex-M4 [3] core specifically designed for embedded applications with high performance, low cost and low power consumption. It can competently cope with more demanding for real-time performance and security of the system, and is welcomed by the industrial market where the system and communication protocol stack become more and more complex.
### 3.2 Design of switch monitoring unit

The switch monitoring unit uses three AD channels of STM32 and conducts polling collection of 48 circuit switch voltage in the power station with three groups of 74HC154 16-1 selectors. With reference to the standard of 48V DC voltage distribution of low-voltage distribution stations, the switch channel’s status can be determined by sampling the partial voltage value of series resistance. The monitoring circuit of the single-circuit switch is shown in Figure 3. When the switch is on and 48V accesses circuit, the sampling value of ADC1_0 is 2.4V after resistor R1 is short-circuited and resistor R2 and R3 are divided. When the switch is off and 12V accesses circuit, the sampling value of ADC1_0 is 0.4V after resistor R1, R2 and R3 are divided. When the branch line connected privately or the detection line is disconnected, 48V assesses circuit and voltage divided by resistor R1, R2 and R3, the sampling value of ADC1_0 is 1.6V. Considering the 1% resistance error of each power type resistor and fluctuations of 40V–60V in the power supply voltage of distribution stations in various regions, the corresponding voltage and status of the switch are shown in Table 1.

![Figure 3. Distribution channel detection circuit](image-url)

| Number | Status         | Display | Range       |
|--------|----------------|---------|-------------|
| 1      | Switch on      | ON      | 2–3.3V      |
| 2      | Switch off     | OFF     | 0–0.8V      |
| 3      | Device disconnection | ABN  | 1.6–2V      |

### 3.3 Selection of environmental monitoring unit

The environment detection unit is based on the SHT11 sensor. The SHT11 is widely used in household weather stations and automatic control fields because of its low energy consumption, strong heat resistance, and high stability. Once the SHT11 sensor detects that the temperature and humidity in the distribution station exceed the preset threshold, the STM32F407 will immediately trigger the rotating light alarm and send out the alarm information through the NB-IoT module [4].

### 3.4 NB-IoT module selection

The NB-IoT module adopts the BC35 module of Quectel Wireless Solutions Company, characterized by high integration, low energy consumption and strong heat resistance that fully meets the requirements of monitoring systems in practical application. In the communication process, different parameters can be set to switch the NB-IoT working state. The three working states that can be switched are connected state, idle state and energy-saving mode. Flexible switching of these three states is also an essential embodiment of the NB-IoT module’s low energy consumption in the subsequent development [5].
3.5 Design of plug device
Each switch monitoring channel is fixed to the gate access terminal with a plug device and two wires. As shown in Figure 4, the structure is simple. The plug device is designed according to the structure of the switch and manufactured by injection molding or FDM process in 3D printing. The bottom surface of the parts coincides with the upper surface of the wire switch to restrict the rotation in the X-axis and Y-axis directions and the movement in the Z-axis direction. The inner side of the parts contact with the round holes of the switch, which restricts the movement in the X-axis direction and the rotation in the Z-axis direction. Raised parts are inserted into holes on the switch, which limits the rotation in the Y-axis direction. Raised parts and holes coordinate for the clearance positioning, convenient for multiple disassembly. And the friction force between the two is sufficient to fix the part because the switch works without external force. Wrap the wire onto the M4 bolts and screw the bolts into the M4 threaded holes on the part, which reduces the complexity of the switch connection and prevents the switch thread from being opened casually.

Figure 4. Insertion device

4. Software design of the system
The system software design is mainly to write ADC sampling function program, TEA algorithm and CoAP protocol wireless communication function research, design the main PC monitoring platform software.

4.1 ADC sampling function programming
In this article, the AD converter of the STM32F407 microprocessor is adopted to monitor three sampling channels in parallel. Take a sampling channel as an example, firstly, the STM32F407 microprocessor sends the start sampling signal and waits for the completion of A/D sampling. Secondly, it reads the A/D data of each branch by shift instruction. Then, the actual value of the external sampling input is read out accurately by using the internal benchmark calculation formula. Finally, the actual value is determined corresponding to the switch’s status and stored in the array [6]. The flow chart of the sampling program design is shown in Figure 5.
4.2 Research on wireless communication function

4.2.1 XTEA algorithm
In order to ensure the security of the data in the network transmission and avoid the data from being peeped or intercepted, as well as to meet the requirements of encryption algorithm in embedded system, such as strong confidentiality of ciphertext and moderate password length, XTEA micro-encryption algorithm is adopted in this article to ensure data security. This algorithm is a kind of symmetric key encryption algorithm, using the key of 64B to encrypt the plaintext data of 32B each time, and finally obtains the ciphertext data of 32B. Relying on the Feistel block encryption model, the left and right shifts and additions are used to encode and decode the data during data encryption [7].

4.2.2 COAP protocol
The monitoring system for low-voltage distribution stations is usually for small amounts of data transmission without complex computation and user interface. Therefore, NB-IoT encapsulates the data into the CoAP protocol packet and sends it to the IoT platform through the UDP transmission protocol, to better meet the requirements of low load and small data. CoAP is a complete binary application layer protocol and its format is compact, whose smallest data packet requires only 4 bytes. The message format is shown in Figure 6. 'Ver', 'T' and 'TKL' respectively represent their version information, message type and Token length. The Code size is 8 bits, divided into the first 3 bits and the last 5 bits, and the first 3 bits represent the type. '0' represents an empty message or request code, and '2' at the beginning represents the response code with the corresponding value. The Message ID represents the Message MID with an ID for each message and the retransmitted MID remains unchanged. The remaining 'Token', 'Option', and 'Payload' are all optional to match for further encryption. After the IoT platform receives the data, it analyzes the CoAP protocol package, stores the data, and the server gets the data on the platform through the data query interface [8].
Figure 6. CoAP message format

4.2.3 Software design of monitoring platform
In order to allow users to read data information more intuitively, the data is visualized by designing a monitoring platform[9], as shown in Figure 7. The main interface of the monitoring platform is divided into two parts: environmental monitoring and switch monitoring. When the station is normal, the monitoring platform’s data will be refreshed once every 24 hours. When the station is abnormal, the monitoring platform will immediately refresh the abnormal data and record the time and information.

From the operation situation, the front-end detects the status of the switch in the distribution station is abnormal or environment condition exceeds the preset threshold, the STM32F407 microprocessor triggers the rotating light alarm after receiving and analyzing the front-end collected signals. And the alarm information is sent to the cloud server by the CoAP protocol. After receiving the alarm information, the user can first disarm the alarm distribution station’s monitoring system, query the alarm status through the button or remote control in the control unit, and then arm the monitoring system of the alarm distribution station after the maintenance is completed.

Figure 7. Monitoring platform

5. Conclusions
The monitoring system for low-voltage distribution station can not only monitor the internal environment of the station and the status of the switch, but also have a certain self-detection function, which can effectively reduce the phenomenon of connecting the branch lines privately. System based
on the XTEA encrypted data algorithm and CoAP protocol transmission is greatly improved in security. The self-designed plug device further simplifies the plug-in complexity. It is believed that in the future the monitoring system will be more and more popular in the market.

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