Research on Status Monitoring and Fault Alarm Device of Drop-out Fuse

Zeli Ju\textsuperscript{1}, Wei Xing\textsuperscript{2}, Wei Duan\textsuperscript{1}, Haofei Sun\textsuperscript{1}, Xin Sun\textsuperscript{3}, Shulin Liu\textsuperscript{4,*}

\textsuperscript{1}State Grid Shaanxi Electric Power Research Institute, Xi’an, China
\textsuperscript{2}State Grid Shaanxi Electric Power Company, Xi’an, China
\textsuperscript{3}State Grid Tongchuan Electric Power Supply Company, Tongchuan, China
\textsuperscript{4}School of Xi’an University of Science & Technology, Xi’an, China

*Corresponding author: ZeliJu@xust.edu.cn

Abstract. Drop-out fuse is a common circuit protection device. When a short fault occurs in the circuit, the fusion pipe will drop and the fuse will be disconnected, so as to isolate the fault line. However, in practical application, there is no reliable means and device for remote monitoring, resulting in the failure information cannot be found in time. Although the traditional drop-out fuse alarm device can play the role of fault alarm. It has the disadvantages of large time difference and high cost. Based on this, a set of status monitoring and alarm device according to the drop characteristics of drop-out fuse after failure has been developed. The inclination and temperature of the fusion pipe are monitored by sensors in real time, and the data is sent to the master station through wireless communication. When a fault occurs, the operation and maintenance staff can be notified in time to repair the fault point. Through experimental demonstration, it can be concluded that the fuse status monitoring and fault alarm device has stable performance, convenient control and high cost performance. If it is applied to the distribution network, it can shorten the outage time, reduce economic losses and increase user satisfaction.

Keywords: Drop-out Fuse, Inclination Angle monitoring, Alarm system, Fault monitoring.

1. Introduction

Drop-out fuse is generally installed on the branch line of 10kv distribution wire, especially at the grid connection point of users and power grid. drop-out fuses are often used as the protection switches to provide a safe working environment for the lines and equipments in the maintenance section [1-2] and increase the safety for maintenance staff. However, the quality of all kinds of drop-out fuses is uneven, and the aging is severe after long-term operation, which leads to many problems such as ineffective drop out and high failure rate [3]. If there is no intelligent equipment or system for real-time monitoring of station area, and there is no reliable means to remotely monitor the operation status of Drop-out Fuse, the information will not be sent to the master station, or the operating and maintenance personnel will not be notified in time after failure. Only when the fuse fails, the electricity consumption of the users is affected, or the station staff patrol the line, the fault point can be found. It greatly increases the loss of
manpower and time [4-5]. Therefore, it is an urgent need to develop a set of intelligent monitoring system which can alarm quickly when a fault occurs. The device described in reference [6-7] can judge its working status by monitoring the current of the fuse, but the device is large in size and complicated to install; the device described in reference [8] has a simple structure, but it can only monitor the inclination angle of the fusion pipe, and the amount of collected data is small, so the reliability is low.

Based on the above problems, a set of status monitoring and fault alarm device for drop-out fuse is developed in this paper. The device relies on the date acquisition unit to monitor the fuse pipe position, temperature and other information, and then the data will be sent to the master station in real time, so as to timely alarm when the fault occurs. In this way, it is convenient for the operating personnel to grasp the fault situation in time, quickly arrive at the fault point for maintenance, and the efficiency of the fuse the timeliness and accuracy of status monitoring can be improved.

2. Working principle of status monitoring and fault alarm device

The moving contacts at both ends of the fuse pipe of drop-out fuse are fastened by fuses. When the short circuit current causes the fuse break [9], the upper and lower moving contacts of the fuse pipe lose the traction of the fuse. Under the action of the gravity of the fuse pipe and the spring leaf of the upper and lower static contacts, the fuse pipe drops rapidly, then the circuit broken and the line or fault equipment in the fault section cut. Therefore, its working state can be judged by monitoring its maximum inclination angle. It is worth noting that the fuse is seriously aged and the sensitivity is reduced after long-term operation [10], which leads to the fusion pipe can not turn to the specified angle; Excessive length of the fuse pipe causes the duckbill to be topped to death, so that the fusion pipe cannot drop smoothly after the pipe is broken [11-13]. These may cause the inclination monitoring to lose its practical effect.

Based on the above problems, a drop-out fuse monitoring and alarm device is developed in this paper. As shown in Figure1, the device is composed of a state acquisition unit and a collection unit. When a short circuit fault occurs, the fuse will fusing due to the high temperature caused by the short circuit current. At the moment, the fusion pipe will drop, and its horizontal angle will change greatly. The state acquisition unit has a built-in angle sensor and a temperature sensor, which can collect the inclination angle and temperature of the fusion pipe. Its wireless communication module sends the detected angle and the highest temperature in this period to the collection unit through short-range wireless RF communication at set intervals. After the collection unit collects the data sent by the status acquisition unit, the data will be processed and analyzed by edge calculating module, and the analysis result will be sent to the master station and the mobile terminal timely via the 4G network. If the analysis result is that the fuse was fused or the fusion pipe dropped, the alarm information will be sent directly to remind the operation and maintenance personnel to repair it quickly. As shown in Figure 2, the date acquisition unit is installed on the fusion pipe of drop-out fuse, and the collection unit is generally installed on the power line tower.

![Figure 1. Working principle of monitoring system.](image-url)
3. System design of status monitoring and fault alarm device

3.1. Parameter design
In this design, the parameter design of fuse status monitoring and fault alarm device is shown in the following table:

| Parameters                                      | Value                                      |
|-------------------------------------------------|--------------------------------------------|
| Line voltage                                     | 10KV                                       |
| Installation angle of fusion pipe                | 65º(±2º)                                   |
| Drop angle of fusion pipe                        | ≤-55º                                      |
| Fuse material                                    | silver-copper alloys (AgCu55)              |
| Fuse melting point                               | 780ºC                                      |
| The maximum temperature of the fusion pipe surface | 100ºC                                      |
| Temperature of fusion pipe Surface during overcurrent | Around 230ºC                              |
| RF communication distance                        | ≥50m                                       |
| Communication mode                               | RF,4G communication                        |
| Monitoring range of Inclination Angle             | -90º~+90º                                  |
| Monitoring range of Temperature                  | -10ºC~250º                                 |

3.2. Date acquisition unit
The date acquisition unit is mainly composed of the following parts: microcomputer control module, power supply module, Inclination Angle monitoring module, temperature monitoring module and wireless communication module. Its composition block diagram is shown in Figure 3.

![Date acquisition unit diagram](image)
3.2.1. **Main control module.** The main control module has mainly responsible for the collection and preliminary processing of data such as inclination angle of fuse and fusion pipe temperature, moreover, wireless communication with the collection unit. It needs high-precision ADC sampling capabilities, fast calculation and processing abilities, and the characteristic of low power consumption. STM32F407ZGT6 micro control chip of ST is used in this design. Its core is 32-bit high-performance ARM Cortex-M4 processor with a clock up to 168MHz. Besides, it supports FPU and DSP instructions, and there are up to 15 communication interfaces, including 3 I2C, 4 USART, 3 SPI, 2 CAN and SDIO interfaces. The inclination angle and temperature sensors are connected with the ADC interface. The ADC module collects analog signals on the acquisition channel and converts them into digital signals. The STM32F407ZGT6 contains three ADCs, which can measure 16 external source signals. Each of them has two data conversion groups, and equip with 16 trigger input channels. The maximum conversion rate of ADC is 2.4MHz and the conversion time is 0.41us, which can meet the requirements of sampling and conversion.

STM32F407ZGT6 micro control chip has the characteristics of high speed, high reliability, low power consumption and strong anti-interference, making it fully meet the control and data processing requirements of this date acquisition unit.

3.2.2. **Inclination Angle monitoring module.** Inclination Angle monitoring module is to obtain the inclination angle of fusion pipe in real time when the drop-out fuse works normally or when there is a fault. The device is designed to use SCA100T biaxial Inclination Angle sensor produced by VTI company in Finland, as shown in Figure 4.

![SCA100T Dual axis Inclination Angle sensor.](image)

SCA100T series is a high-precision biaxial inclination angle sensor chip based on 3D-MEMS, and it provides the performance of horizontal measurement instrument level. The dual axes of the sensor elements of the sensor chip are perpendicular to each other and need to be parallel to the measurement platform when measuring. The internal damping of the sensing element is increased, so it is insensitive to high frequency vibration and can withstand mechanical impact force up to 20000g. The angle measuring range is ±90° and the resolution can reach 0.0025°, in addition, it uses analog voltage output. The formula for converting analog output voltage into angle is

\[
\alpha = \arcsin\left(\frac{V_{\text{out}} - \text{offset}}{\text{sensitivity}}\right)
\]  

Where offset is the output voltage (2.5V) at 0°, sensitivity is the chip sensitivity (4V/g), and \(V_{\text{out}}\) is the analog output of the chip. SCA100T inclination sensor has the characteristics of weak temperature dependence, high resolution, low noise and sound sensor element design, which can meet the real-time measurement and data acquisition of the inclination angle of the fusion pipe.

3.2.3. **Temperature monitoring module.** The moving contacts at both ends of the fuse pipe of drop-out fuse are fastened by the fuse wire. The rated current of the fuse wire should be less than or equal to the
rated current of the fuse, which can be 1.5–2 times of the rated load current [14]. When a short-circuit fault occurs in the circuit, the fuse wire will fuse due to the high temperature caused by the short-circuit current. At this time, the fusion pipe will drop, and the line in the fault section can be cut off. If the fuse aging seriously after long-term operation, it may cause the fuse fused but the fusion pipe does not drop. In order to avoid it happening, we can judge whether the fuse wire is fused by monitoring the real-time temperature of the fusion pipe, as an auxiliary means to monitor the working status of the fuse. The device is designed to use K-type thermocouple temperature sensor module, which is composed of K-type thermocouple and MAX31855 thermocouple digital output converter, as shown in Figure 5.

![Figure 5. K-type thermocouple temperature sensor module.](image_url)

Max31855 thermocouple digital output converter with cold junction compensation can convert K,J,N,T,E thermocouple signal into digital quantity. The module outputs 14 bit signed data in read-only format through simple SPI compatible interface. The power supply voltage range of the converter is 2.7–5.5V, the output voltage range is -6~+20mV, the temperature resolution is 0.25 ℃, the maximum temperature reading is +1800 ℃, the minimum temperature reading is -270 ℃. For K-type thermocouple, the temperature range is -200 ℃ to +700 ℃, maintaining ±2 ℃ accuracy. During normal operation, the voltage changes according to the law of about 41μV/℃, and the thermocouple characteristics are approximated according to the following linear equation:

$$V_{out} = (41.276FV/NC) \times (T_R - T_{AMB})$$

(2)

Among them, $V_{out}$ is the output voltage of thermocouple (μV), $T_R$ is the junction temperature of remote thermocouple(℃), $T_{AMB}$ is the device temperature (℃). From the above analysis, the K-type thermocouple temperature sensor module can meet the design requirements.

3.2.4. Wireless RF transceiver module. As shown in Figure 6, the main control module preliminarily processes the data collected by the sensor, and then sends it to the collection unit by the wireless communication module. Due to the distance between the date acquisition unit and the collection unit is generally close, and the long-time reliable work needs to be met by the date acquisition unit. Therefore, the device adopts the short distance, low power consumption, wireless RF communication mode. The data interaction and real-time communication between the date acquisition unit data and the collection unit are realized.

![Figure 6. Wireless RF communication.](image_url)
NRF24L01 wireless transceiver module is a 2.4-2.5GHz RF transceiver module with NRF24L01 single chip wireless transceiver chip. It’s output power channel selection and protocol setting can be set through SPI interface. The working voltage range is 1.9V~3.6V, and the input pin can withstand 5V voltage input at most. It has 126 communication channels and 6 data channels, the requirements of multipoint communication and FM can be met. When working in the transmitting mode, the current consumption is 9.0mA when the transmitting power is -6dBm, 11.3mA when the maximum transmitting power is 0dBm, 12.3mA when it is receiving mode, and the current consumption is lower in the standby mode. In outdoor, the communication distance of NRF24L01 is up to 62m, the design requirements can be met.

3.3. Collection unit
The collection unit is responsible for collecting the data of the date acquisition unit, then the data are processed and analyzed through the edge calculation module. Moreover, reporting the analysis results to both the master station and the mobile terminal through the 4G network. It is mainly composed of the following parts: control processing module, power supply module, data storage module, Wireless RF Transceiver module, 4G communication module. The composition block diagram is shown in Figure 7.

![Figure 7. Composition of Collection unit.](image)

Power supply module. In addition to communicating with the date acquisition unit, the master station and the mobile terminal, the aggregation module must be able to process more data, so it needs to be equipped with a continuous and reliable power supply. The power module of this design selects the common mobile phone lithium battery and solar panel to provide working power for the device, so as the requirements of long-term field application of the collection unit are met. The lithium battery uses standard mobile phone lithium battery and battery slot plate which is 3.8 V, 1500 mA. The solar panel parameters are as follows: The size is 250mm×160mm×3mm, the output power is 6W, the output current is 1A, and the output voltage is 6V. When the device is operating normally, the necessary power for operation is provided by the lithium battery. And if the voltage of lithium battery is insufficient, it will be charged by solar energy to ensure a stable output voltage. the requirements of continuous operation are met.

Control processing module. The control processing module is mainly responsible for analyzing and edge calculation of the data sent by the date acquisition unit, thereby the working status of the fuse is judged and whether to alarm is deciding. In addition, the wireless 4G communication module must be controlled in order to upload data and real-time information to the master station and mobile terminal. Microelectronics' STM32F767IGT6 control chip is used by the design. This control chip is a kind of ultrahigh performance MCU equipped with ARM Cortex-M7 core, with up to 512KB general data memory, including the tightly coupled data memory (DTCM) up to 128KB. Its working voltage is 1.7V-3.6V, the number of CPU bits is 32-Bit, and the main frequency is 216MHz. The design requirements can be basically met by the ultra-high computing performance.
4G communication module. WHLTE7S4 V2 is a compact and feature-rich M2M4G product. It is not only suitable for 4G of China Mobile, China Unicom and Telecom, but also suitable for China Mobile, China Unicom 3G and 2G network standards. This module developed based on the embedded Linux system, with high reliability and high ease of use, and it can be integrated into its own system easily and quickly. The design parameters for this module are shown in Table 2.

| Function                  | Parameter                  |
|---------------------------|----------------------------|
| size                      | 44.4mm×41.8mm×12.5mm       |
| Supply voltage            | 3.4V-4.2V                  |
| Operating temperature     | -20℃~+70℃                 |
| Parameter configuration   | Serial Interface /AT instruction |
| Operating system          | windows/linux/Android      |
| Support network           | GSM/4G                     |
| Way of control            | AT instruction             |
| Certification             | China TA/CCC               |

The module has complete software functions. Two-way data transparent transmission from serial port to network can be achieved. It supports 2-way Socket connection, httpd, UDC and other protocol communication. In addition, it has the characteristics of high speed, low delay etc, therefore this design requirement can be met.

3.4. Software design
In the research of drop-out fuse status monitoring and alarm device, the integrated environment of STM32 MCU selects the Embedded workbench for ARM which developed by IAR, and referred to as IAR. All of the ARM processors and the Integrated development environment of microprocessors of many well-known semiconductor companies can be supported, the project manager, editor, C/C+ compiler, assembler, connector, and debugger are included.

Edge computing module main program. After the collection unit receives the data sent by the date acquisition unit, then the data are processed and analyzed by edge computing. And The main process is shown in figure 8.

![Figure 8. Edge computing flowchart.](image)
The data is received by the collection unit through the wireless radio frequency communication module, and it is analyzed by the edge computing module. The specific process is as follows: First of all, judging whether the horizontal angle of the fusion pipe is greater than the threshold value (it can be set to -90°-+90°). If the horizontal angle of the fusion pipe is less than the threshold value, it will be considered that the fusion pipe fell, then an alarm message will be sent immediately. If the inclination angle is greater than the threshold value, then judge whether the temperature (fusion pipe temperature) exceeds the threshold value. If the temperature exceeds that value, it will be judged that the fuse is broken but the fusion pipe does not fall, and an alarm message will be sent immediately. If there is no above situation, the work is normal. No alarm message will be sent. If none of the above situations occurred, it means the device works normally, and no alarm message will be sent.

4. System testing of status monitoring and fault alarm device

According to the design of the fuse state monitoring and fault alarm device in this article, the system test environment is constructed. By testing the operation of the system when the fuse is in different states, the reliability and accuracy of the system are judged. In this experiment, the inclination angle threshold of the fusion pipe is set to 50°, and the surface temperature threshold of the fusion pipe is set to 105℃. The system judgment result is shown in Table 3. Through the test, the working status of the fuse can be monitored effectively.

Table 3. Monitoring of fusion pipe working status.

| Horizontal angle of fusion pipe /° | Surface temperature of fusion pipe /℃ | State judgment                  |
|----------------------------------|--------------------------------------|---------------------------------|
| 65                               | 25                                   | Normal                          |
| 65                               | 50                                   | Normal                          |
| 65                               | 75                                   | Normal                          |
| 65                               | 185                                  | Fuse blown/Fusion pipe didn’t drop |
| 65                               | 220                                  | Fuse blown/Fusion pipe didn’t drop |
| 60                               | 220                                  | Fuse blown/Fusion pipe didn’t drop |
| 45                               | 75                                   | dropped                         |
| 25                               | 95                                   | dropped                         |
| 5                                | 125                                  | dropped                         |
| -25                              | 150                                  | dropped                         |
| -45                              | 175                                  | dropped                         |
| -65                              | 200                                  | dropped                         |

5. Conclusions

In this paper, a status monitoring and fault alarm device of fuse is designed. The short-distance wireless RF communication is adopted between the date acquisition unit and the collection unit, and 4G communication is adopted between the collection unit and the master station and mobile terminal. This method has the advantages of high information transmission efficiency, small time difference, fast fault handling speed, and high timeliness. The temperature and inclination angle of the fusion pipe are sent to the collection unit for comprehensive research and judgment, the accuracy of the results can also be improved. This design eliminates the problems of line insulation and safety distance. The reliability, flexibility, and applicability of the system are enhanced. While Not only is a lot of network communication costs saved, but also the authenticity and reliability of data sources are guaranteed. In addition, the design is simple in structure, reliable in work, and easy to install. The working state of the drop-out fuse can be automatically detected, and it has high fault detection accuracy and perfect fault information processing ability.

With the progress of intelligent power distribution, the drop-out fuse must have reliable monitoring means and devices. When this device is applied to the distribution network, the real-time status of drop fuses can be better monitored. Moreover, it is beneficial to the stable and safe operation of the drop-out
fuse, and the staff can find out the fault as soon as possible. Therefore, it has economic and social significance to a large extent.

References
[1] Wang Jinhui, Wang Feiming, Zhao Yisong, Cause Analysis of Failure in Breaking Test of 12kV Outdoor Drop Jet Fuse, Northeast Electric Power Technology, 2020.41 (09): 39-44.
[2] Deng Zhihao, Research on the Operation Convenience of High Voltage Drop-out Fuse, Technology & Market, 2020.27 (11): 125-126.
[3] Yang Wenhao, Yang Aihua, Wang Wencong, 10kV outdoor AC high voltage drop jet fuse, Rural Electrification, 2018, (3): 70-72.
[4] Cheng Liang, Cui Shaopeng, Wang Hongtao, Improvement of the fuse of 10kV drop-out fuse, Rural Electrification, 2014.(12): 50-51.
[5] Zhou Jianke, Wang Zhen, Gao Yibo, Research on the Main Problems in the Operation of Drop-out Fuse, Technology and Economic Guide, 2020. 28 (05): 17-19.
[6] Li Maogen, Wang Yangang, Xue Sai, Liang Huayin, Intelligent early warning device for drop-out fuse, Rural electrician, 2020. 28 (01): 29-30.
[7] Shang Aiyang, Han Chao, Jiang Wenxiu, Research and Application of Alarm Device for High Voltage Drop-out fuse, Innovation field, 2020: 92-93.
[8] Zhou Xiang, Ding Yongsheng, Zhu Feng, Development and application of drop-out fuse monitoring system based on three-axis accelerometer, Electrical Technology, 2018, (05): 49-52.
[9] Jin Yuanyuan, Wang Feiming, Cheng Hui, Li Xingyu, Characteristic Analysis and Test Method of Pre-arc Seconds Characteristic of 12kV Drop-out Fuse, IEEE ICPRE, 2020: 25-26.
[10] Li Zhiquan, Li Mingchao, Li Shoupeng, Troubleshooting and preventive measures for frequent fusing accidents of drop-out fuses, Rural Electrification, 2019. (06): 42-45.
[11] Yang Huizhi, Analysis of solutions to the failure of 10kV Drop-out fuse tube drop and blow, Communication power technology, 2018.35 (06): 184-185.
[12] Wang Feiming, Zhao Qi, Zhao Yisong, Analysis and research on 10kV drop-out fuse material and temperature rise experiment, High Voltage Apparatus, 2019.55(07): 81-86.
[13] Li Xingyu, Wang Feiming, Cheng Hui, Analysis of Material and Temperature Rise Test of 10kV Drop-out Fuse, IEEE ICPRE, 020: 81-86.
[14] Wu Changhao, Wu Jiafeng, Common faults and preventive measures of drop-out fuse, Rural electrician, 2019.27 (01): 43-43.