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Automatic Fire Extinguishing Control System for Main Transformers Based on Water Spray Technology

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Abstract: With the advancement of power systems, large oil-immersed transformers play a critical role in ensuring grid stability. However, transformer fires caused by internal faults pose significant risks, including explosions and widespread power outages. This study proposes an automatic water spray fire extinguishing system to address these challenges. The system integrates real-time fire detection, automated water spray activation, and a dual-pump redundancy mechanism. Key components include temperature/smoke sensors, an AT89C52 microcontroller, and a water spray network. The system's design emphasizes rapid response, cooling effects, and oxygen isolation through fine water mist. Experimental validation confirms its effectiveness in suppressing fires within 60 seconds, reducing potential losses by 90% compared to manual interventions. This solution enhances the safety and reliability of high-voltage transformers, offering practical value for power infrastructure protection.

Keywords: Transformer; Water spray fire extinguishing; Automatic control; Fire detection; Microcontroller

1. INTRODUCTION

Large oil-immersed transformers are vital in power grids but are prone to fires due to insulation aging, oil decomposition, and electrical faults. Statistics indicate that transformer fires account for 15% of power system accidents, often leading to catastrophic economic and environmental consequences. Traditional fire suppression methods, such as foam or nitrogen injection, face limitations in automation and efficiency. This study focuses on a water spray-based automatic fire control system, leveraging its advantages in cooling, oxygen isolation, and cost-effectiveness.

In the power system, ultra-large oil-immersed transformers with voltage levels of 220kV and higher occupy a pivotal position as one of the core power equipment. With the vigorous development of the national power industry and the gradual construction of ultra-high voltage power grids, ensuring the stable and reliable operation of these transformers has become the cornerstone of maintaining the stable operation of the entire power system. Among the many potential transformer failures, fire is undoubtedly the most serious and urgent. Once the internal fire of the transformer occurs, the internal oil temperature often far exceeds the flash point during normal operation, and is very likely to approach or even exceed the re-ignition temperature, which brings great threats to the safety and stability of the power system. Therefore, the study of the prevention and countermeasures of transformer fire is of vital significance to ensure the safe and stable operation of the power system. Once it encounters air, it can deflagrate, which is difficult to control and causes more serious damage. This situation poses a serious threat to the stable operation of the power system and socio-economic development. Therefore, according to the actual situation of the environment where the transformer is located, the corresponding automatic fire extinguishing control system is studied and designed, which aims to extinguish the fire in the early stage of the fire and effectively prevent the serious fire explosion accident of the transformer, which is of great significance to the safe operation and economy of the power system.

Currently, most substations are in unattended mode, which leads to a slow processing speed in the event of a fire. While preventing fires on a daily basis, strengthening fire protection measures has become a basic requirement for the fire extinguishing system of the main transformer of the substation. Therefore, it is important to choose a safe, reliable and economical fire extinguishing device that is suitable for the transformer manufacturing process and in line with the actual environment. With the expansion of the scale of the substation, the water spray fire extinguishing system, the "SP" synthetic foam spray fire extinguishing system and the oil and nitrogen injection fire extinguishing system are the three main transformer fire extinguishing systems.[1]

2. THE OVERALL DESIGN OF THE SYSTEM

The system is mainly composed of data detection, ADC conversion, single-chip microcomputer control circuit, display circuit, clock circuit, main and standby motor circuit, and the overall design scheme is shown in Figure 1.

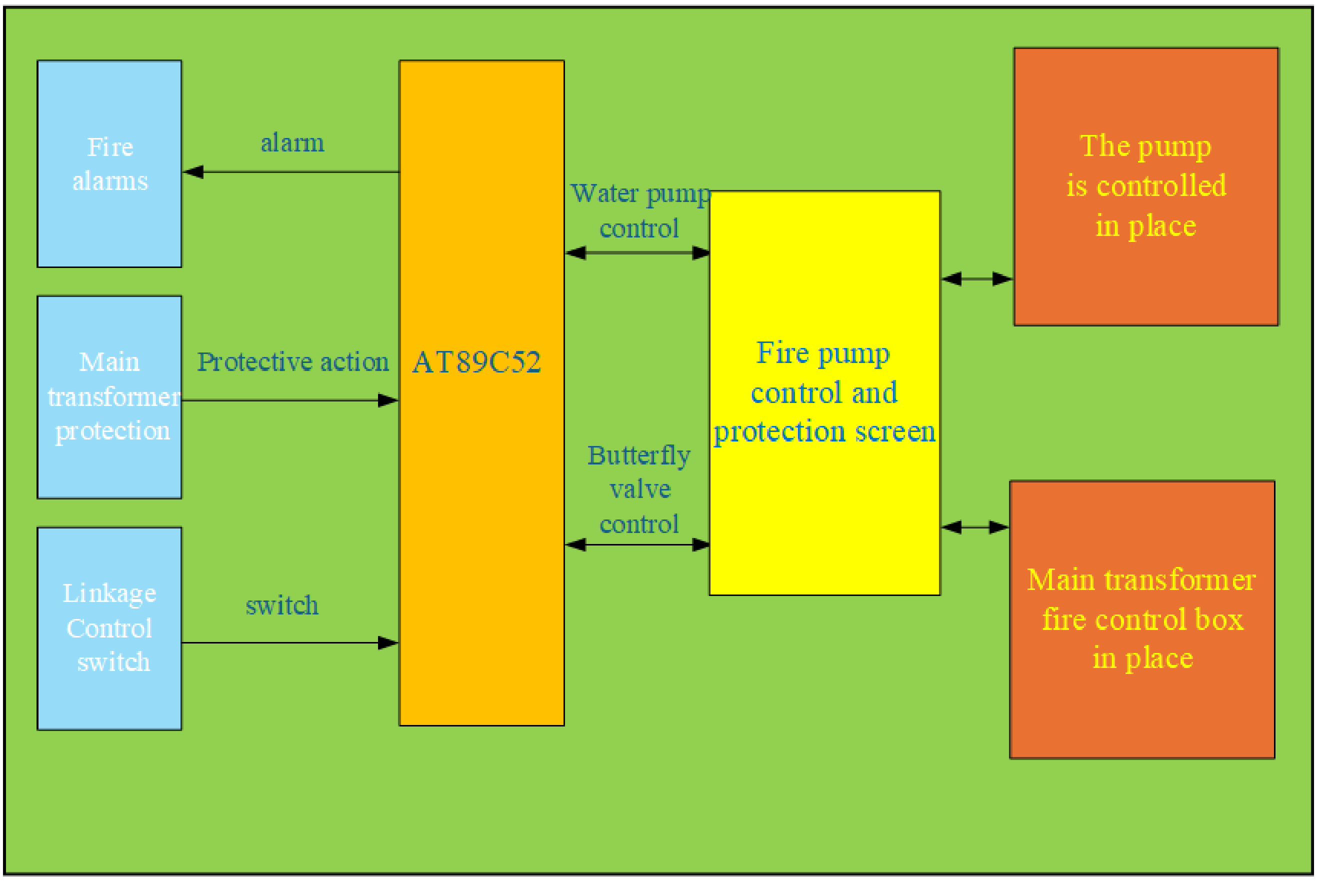

Figure. 1 Block diagram of water spray fire extinguishing system

The automatic fire extinguishing control system is mainly controlled by PLC and single-chip microcomputer. There are a few things to consider when choosing:
(1) Flexibility and scalability: PLC systems usually have strong flexibility and scalability, and can easily adapt to different control needs and system scales. Moreover, the PLC can support a variety of input and output modules, which can be easily integrated with other devices, such as sensors, actuators, etc., to achieve complex control logic. The flexibility of the microcontroller system is relatively low, and it usually needs to be customized and developed according to specific needs, and it is difficult to expand the function. The input and output of microcontrollers are usually limited and may not be sufficient to meet complex control needs.
(2) Real-time and response speed: PLC systems usually have high real-time and fast response speed, which is suitable for automatic control systems that need rapid response. PLCs typically have dedicated real-time operating systems and high-speed processors that are able to execute control logic at high speeds. The real-time performance and response speed of the single-chip microcomputer system depends on its hardware performance and software design, and the single-chip microcomputer system is enough to meet the needs in some application scenarios where the response speed requirements are not particularly high.
(3) Development and maintenance costs: PLC systems usually have high development and maintenance costs, and the price of hardware equipment is higher. However, PLC systems have relatively short development cycles and low maintenance costs. Microcontroller systems are likely to be less expensive to develop because of the relatively low price of hardware devices and the relative availability of development tools and resources. However, microcontroller systems can have long development cycles and high maintenance costs, especially when systems need to be updated and upgraded.
Considering all these factors, the choice of PLC or microcontroller as the control core of an automatic fire extinguishing control system depends on specific application needs, budget constraints, and available resources. For industrial applications and other scenarios that require high real-time, reliability, and flexibility, PLCs may be a better choice. For simple control tasks or projects with limited budgets, a microcontroller system may be more suitable.

The intelligent fire control system automatically activates the alarm mechanism at the initial stage of a fire. The system consists of several key components, including an intelligent fire control panel, a fire field control box, and a pump room control box. It has an efficient automatic fire detection capability, which can convert detected physical signals such as temperature and smoke into electrical signals in real time, which are then quickly transmitted to the alarm controller. Once the preset alarm threshold is reached, the alarm controller will quickly trigger the alarm to send out a clear and loud alarm signal so that personnel can be notified to take corresponding emergency measures in time. At the same time, it can start the fire extinguishing system in time, take effective measures to extinguish the initial fire, and record the location and time of the fire. By connecting the control bus and protection signals to the intelligent fire control panel and connecting with the computer, the control function of the intelligent fire protection system is realized; In order to optimize the operation of the fire protection system, we first connect the temperature detector to the control box at the fire scene to ensure that there is a seamless signal exchange and transmission between them. As soon as the temperature detector detects an abnormal

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temperature, the control box immediately initiates the corresponding response mechanism, which includes

the activation of the fire pump and the water spray valve, so as to quickly respond to the potential fire risk. In addition, the pump room control boxplays a crucial role in the overall system. It provides an interface for manual control of internal electrical equipment, allowing users to operate flexibly according to the actual situation. At the same time, the control box of the pump room also has the status display function, which reflects the operation status of the electrical equipment in real time, which provides great convenience for the commissioning and maintenance of the system. This design not only improves the automation and fire extinguishing reliability of the fire protection system, but also greatly reduces the losses caused by fires. Functions of the intelligent fire control system:

(1) It has the functions of online programming, detection and debugging.

(2) The alarm conditions of the detector can be changed according to the actual situation of the system.

(3) It has the function of information memory preservation, which provides an important basis for subsequent accident analysis.

(4) The temperature detection loop has a self-test function, and it should be able to send a signal when the loop fails.

(5) The system equipment can be self-checked regularly, and the fault can be found in time and the alarm is displayed.[2]

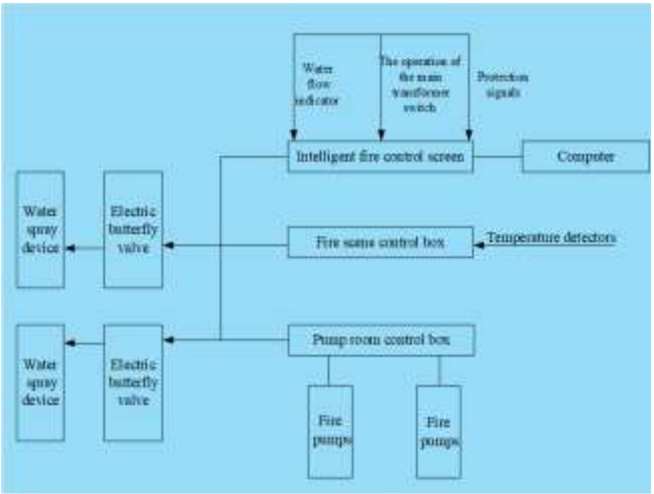


Figure. 2 Smart water spray system

3. The HARDWARE PART OF THE SYSTEM IS COMPOESD

3.1 System Power Supply Design

Because the industrial site is generally 220V alternating current, and the sensing part of the single-chip microcomputer needs a 5V DC power supply, and the solenoid valve needs a 12V DC current, therefore, an AC/DC conversion circuit must be set up to obtain a suitable DC power supply.

Figure. 3 Power supply block diagram

Design the power supply according to the power supply block diagram

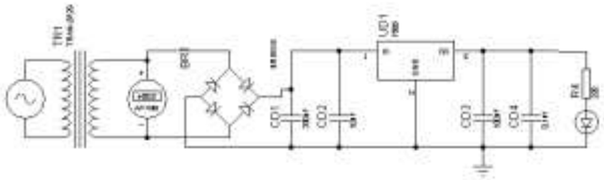


Figure. 4 Power supply circuit diagram

3.2 The System Displays Sections

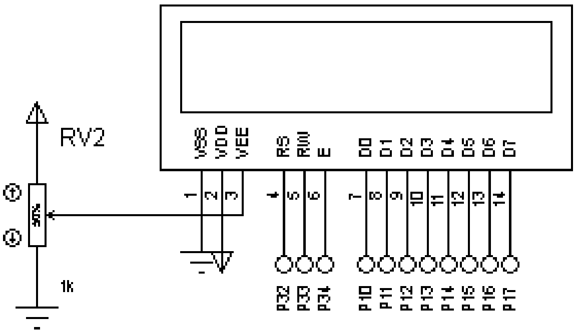


Figure. 5 Displays part of the circuit

3.2.1 Structure And Function

LM016L LCD screen, as a device focusing on the display of numbers and letters, has excellent display functions. In addition to the basic character display, it can also realize the dynamic effects of characters through the controller, such as movement and flashing, to bring users a richer visual experience. The display has a compact design with 14 pins and the ability to display up to 32 characters in a limited space, with cleverly spaced between characters for clearer display. The advantages of the LM016L LCD display are significant, such as its high-quality display, easy operation, compact design, light weight, and low power consumption, making it an ideal choice for a wide range of applications. It's worth noting that the display also offers a backlight option, with or without a backlight depending on your needs. Although the version without a backlight is thinner and lighter in appearance, in practical applications, the presence or absence of a backlight will not have much impact on the display.

3.2.2 LM016L Interface Circuit With Microcontroller

The microcontroller AT89C52 and character display LM016L form part of the display part of the circuit. The microcontroller is responsible for reading and writing data and executing display commands. The P1 port of the MCU is connected to the D0-D7 data port of the LM016L. The RS, R/W, and E terminals of the LM016L are connected to the P3.2 to P3.4 pins of the MCU respectively. The other control side of the display is connected to the power supply, the VSS is connected to ground, and the VEE is connected to a resistor. In addition, four switches are connected to the P2.4 to P2.7 ports of the microcontroller to switch the temperature, smoke concentration page and date page in the display, and modify the date settings.

3.3 Sensing Section

The design adopts analog smoke, and the analog temperature is converted into a digital signal through the ADC0832, and the alarm conditions are: the smoke concentration exceeds 5%, and the temperature exceeds 50 °C.

(1)Structure and function of ADC0832

ADC0832 is an 8-bit resolution, dual-channel A/D conversion chip. General analogue conversion requirements apply. It is connected to the microcontroller through a three-wire interface.

(2)ADC0832 control principle

In the non-operating state of the ADC0832 chip, the CS input should be kept high to ensure that the chip is disabled. At the same time, the CLK and DO/DI terminals allow arbitrary levels to be maintained without special settings. However, when performing the A/D conversion operation, the chip-selectable enable CS must be set low to ensure that the chip can function properly. In addition, it is necessary to supply the clock pulse signal through the CLK terminal, and use the DI terminal to select the input path of the data signal to ensure the accuracy and efficiency of data conversion.

(3)Circuit connection with single-chip microcomputer

Generally speaking, there are four ports for the connection between the ADC0832 chip and the microcontroller, namely the CS side, the CLK side, the DI side and the DO port. However, since the DI and DO ports are not simultaneous and bidirectional interfaces when communicating with the microcontroller, they can be connected in parallel and reused in practical applications. For example, the CS terminal of the ADC0832 chip is connected to the chip selection enable terminal and connected to the P2.3 port of the single-chip microcomputer, the analog smoke and temperature are connected to the CH0 and CH1 channels respectively, the clock signal terminal CLK of the ADC0832 is connected to the P2.0 port of the single-chip microcomputer, and the DO and DI ports are connected in parallel to the P2.1 port of the single-chip microcomputer.The P3.7 port of the single-chip microcomputer is connected to the buzzer for alarm, and the condition for the buzzer to send out an audible alarm is that the smoke concentration exceeds 5% or the temperature exceeds 50 °C.

3.3 Clock Inspection Section

In this design, we used the DS1302 to check the circuit and provide seconds, minutes, hours, and date timing functions. In addition, it automatically adjusts the number of days per month, leap year compensation, etc. When the timer reaches half past ten in the morning on the first day of each month, it will send a signal to the microcontroller, and the microcontroller will control the circuit to complete the automatic inspection. After the inspection is completed, the timer will continue to clock until the next inspection time.

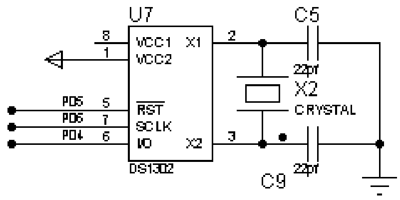


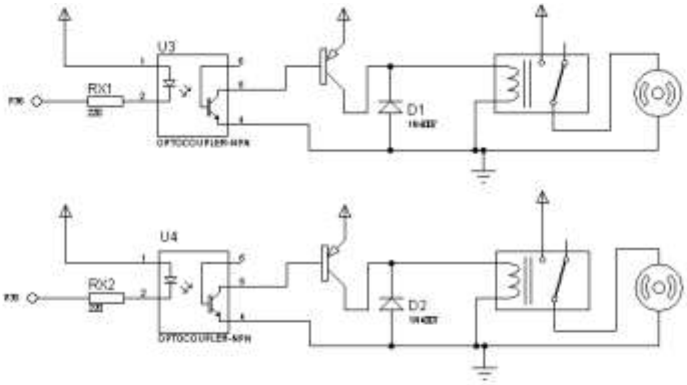
Figure. 6 Clock inspection section

(1)Structure and introduction of the DS1302

The DS1302 is a clock chip that integrates a real-time clock and RAM registers that temporarily store data. It communicates serially with the microcontroller through three interfaces: RES reset interface, I/O data line and SCLK serial clock. It is worth noting that it consumes very little power and consumes less power during work. In addition, it operates from 2.5V to 5.5V. Due to its characteristics, the DS1302 has a wide range of applications in telephone, fax, and timing instruments.

(2)How the DS1302 works basically

The internal structure of the clock chip is similar to that shown in Figure 17. Vcc2 is used as the main power supply and Vcc1 is used as the backup power supply, so the chip can continue to operate even when the main power is turned off. When Vcc2 > Vcc1 0.2V, the power supply is provided by Vcc2. The X1 and X2 pins are connected to an indirect crystal oscillator with a frequency of 32.768kHz, providing an accurate clock reference for the chip. The RST is a reset pin whose input drive signal must be set to "1" to initiate data transmission. Only when RST is "1" is it allowed to operate on the clock chip to initialize all data transmissions. If the level of the reset terminal is set to "0" during transmission, the data transmission will be interrupted and the I/O pins will be in a high-impedance state. Generally, when connecting with the I/O port of a single-chip microcomputer, a pull resistor needs to be added to improve the driving ability of the I/O port and ensure signal stability and timing accuracy. RST



can only be set high when the SCLK is low.

3.4 AT89C52

The AT89C52 of this design is the core part, which is in charge of all chips to realize the automatic control function.AT89C52 is a microprocessor characterized by low power consumption and high performance. The speed of the processor is 24MHz, the operating range of the power supply voltage is 4v~5.5v, and the operating temperature of the chip is -40°C~ 85°C. It has a number of functions, including initialization of the internal registers of the convergence IC, data RAM, and external interfaces.[3]

3.5 Main and Standby Motors

Figure. 7 Circuit diagram of the main and standby motors

The main and standby motor circuits mainly use a photocoupler, which is a device that combines light-emitting and photosensitive elements to realize the conversion of photoelectric signals. Specifically, when an electrical signal is fed into its port, the built-in light-emitting diode emits light, which then hits the light-sensitive element, causing an electric current to be generated and the diode to be turned on. Conversely, if the input fails to receive an electrical signal, the light-emitting diode does not emit light, leaving the diode in a non-conducting state. The design of the optocoupler is unique in that it has a small input impedance, typically only a few hundred ohms, and there is no direct electrical connection between the input and output circuits. This design enables the photocoupler to effectively suppress the spire pulse and various noise interference during signal transmission, thus ensuring the stability and independence of the circuit and further improving the reliability of the overall system.[4]

4. SOFTWARE FLOW DIAGRAM OF THE MAIN TRANSFORMER FIRE EXTINGUISHING SYSTEM

The clock inspection and sensing alarm circuit part of the main transformer fire extinguishing control system are mainly controlled by single-chip microcomputer. As soon as a smoke concentration or temperature is detected to reach an alarm value, it is considered a fire in the main transformer. These signals are converted into electrical signals by the converter, and the P3.7 pin is controlled by the single-chip microcomputer to trigger the buzzer for alarm.[5]

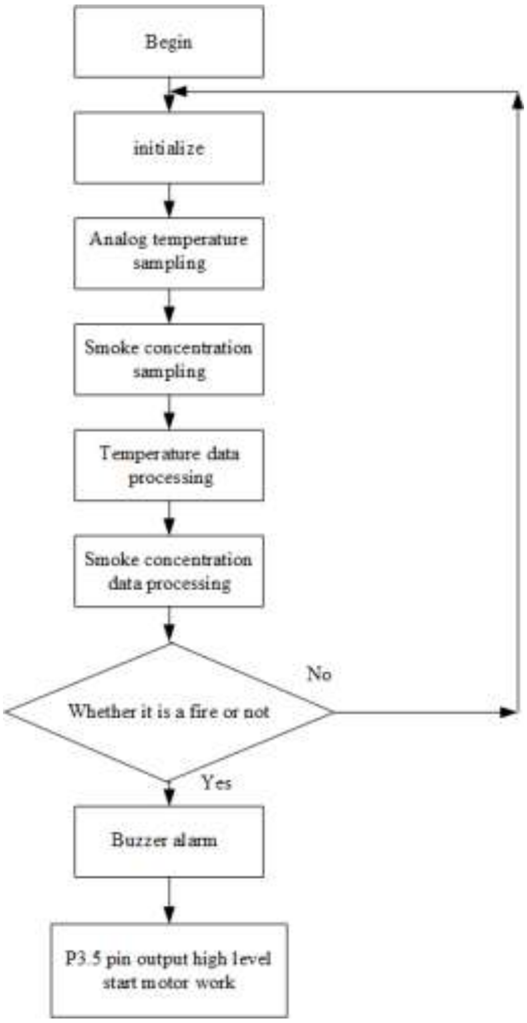


Figure. 8 Flow chart of the sensing alarm part

5. CONCLUSION

Through the above demonstration and design, I believe that the main functions of the alarm of the automatic water spray fire extinguishing control system of the main transformer, the automatic inspection of the fire circuit and the switching of the main and standby motors of the fire fighting equipment can be basically realized. The design of the hardware circuit is feasible and reliable. However, in the process of design, due to the constraints of various conditions and the limitation of technical level, there are still some deficiencies in practical application, such as the selection of nozzles of the water spray system, the requirements of water supply and power supply, the layout of pipeline valves and the software design.

6. REFERENCES

[1] Kemin. Development and application of automatic fire ext inguishing device for power transformer[J].Electrical Expl osion Protection,2024,(05):24-27.DOI:10.14023/j.cnki.dqf b.2024.05.007.

[2] Wang Zhihui,Que Xinggui. Research on automatic foam s pray fire extinguishing device for large transformer[C]//Ch ina Association for Science and Technology. Energy Cons

ervation and Environmental Protection and Harmonious Development - Proceedings of the 2007 Annual Conference of China Association for Science and Technology (4).Shanghai Fire Research Institute, Ministry of Public Security; Shanghai Fire Research Institute, Ministry of Public Security; ,2007:400-404.

[3] Howard M.Berlin，《555 Timer Applications Sourcebook》[M].the United State of America，1980

[4] Scott.R.F，《555 Timer IC Application》[M].Radio Electronics，1985

[5] Rudolf.Graf，《the Encyclopedia of Electronic Circuits》[M].Tab Books Inc.，1985

APPENDIX