

Research on Novel Thermal Relay Overload Protection (Postprint)

Authors: Zong Ming, Gong He

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Abstract

The traditional mechanism of thermal relay overload protection relies on the thermal bending characteristics of bimetallic strips. However, due to significant dispersion in bimetallic strip materials and properties, limited inverse-time characteristics, large adjustment errors, poor repeatability, and susceptibility to environmental temperature influences that cause false tripping or failure to operate, it is difficult to meet contemporary overload protection requirements. To ensure safe and reliable operation of AC motors, research on the electronic and intelligentization of thermal relays is required. This paper proposes a control principle for a novel thermal relay and experimentally verifies its feasibility, thereby opening a new avenue for motor thermal protection.

Full Text

Research on Overload Protection of New Type Thermal Relay

Zong Ming, Gong He

(School of Electrical Engineering, Shenyang University of Technology, Shenyang 110870, China)

Abstract

The traditional overload protection mechanism of thermal relays relies on the thermally induced bending characteristics of bimetallic strips. However, due to significant material property variations of bimetallic strips, limited inverse-time characteristics, large adjustment errors, poor repeatability, and susceptibility to environmental temperature causing false or failed operations, it is difficult to meet current overload protection requirements. To ensure safe and reliable operation of AC motors, research on electronic and intelligent thermal relays is necessary. This paper proposes a novel control principle for thermal relays and

verifies its feasibility through experiments, opening a new pathway for motor thermal protection.

Keywords: New thermal relay, motor overload protection, control theory, intelligent research

Zong Ming (male, born 1957) is a professor and doctoral supervisor. His research interests include special motors and their control, and intelligent electrical apparatus.

Gong He (female, born 1991) is a master's student. Her research interests include electrical apparatus design and key technologies.

1 Introduction

Thermal relays are primarily used for motor overload protection, phase-loss protection, and asymmetrical protection. Motors are devices that convert electrical energy into mechanical energy, serving as the power source to drive various production machinery. They constitute a critical guarantee for normal operations in industry, agriculture, national defense construction, and daily life [1]. According to incomplete statistics, motor power consumption accounts for over 70% of total grid electricity generation, making them the most widely used power equipment in industrial, agricultural, and commercial systems. However, incidents of motor burnout due to faults and even major safety accidents occur every year. Therefore, to ensure normal motor operation, overload protection by thermal relays is extremely important [2-4].

The thermal tripping method using bimetallic strips offers simplicity, compact size, and low cost, and can achieve inverse-time protection characteristics to a certain extent [5]. However, due to large dispersion in bimetallic strip materials and characteristics, single inverse-time characteristics, large adjustment errors, poor repeatability, and susceptibility to environmental temperature causing false or failed operations, it is difficult to meet current overload protection requirements [6-9]. Additionally, thermal relays using bimetallic strips have another major disadvantage—reset waiting. That is, if the relay has tripped due to bimetallic strip bending during an overload, the line cannot be re-energized until the bimetallic strip cools down, as temperature changes require time [10].

The emergence of electronic thermal relays [11-12] has solved the shortcomings of traditional thermal relays but has simultaneously introduced new problems, namely the need for a current transformer as a tool to measure line current. Current transformers have iron cores, large volume, and are prone to saturation, which limits the intelligent development of thermal relays [13-14].

2 Theoretical Analysis and Control System

2.1 Control System

The overload protection of thermal relays is divided into two types: thermal protection and electronic overcurrent protection. Thermal protection converts overload current into temperature through heating elements, using bimetallic strips to achieve overload tripping. Electronic overcurrent protection uses current sensors to detect overload current, cooperating with a microcontroller system to achieve overload protection. This project combines traditional bimetallic strip thermal protection and electronic overcurrent protection (referred to as thermo-electric hybrid overload protection), as shown in Figure 1 [Figure 1: see original paper]. Temperature sensors replace the bimetallic strips in thermal protection, while the combination of heating elements and temperature sensors replaces the current transformers in electronic overcurrent protection. First, heating element 1 reflects the current. Insulating material 2 is a thermally conductive insulating material that transfers temperature to temperature sensor 3. Temperature sensor 3 then converts temperature into electrical signals. Considering the influence of ambient temperature, compensation temperature sensor 4 is used for correction. Finally, the electrical signals are transmitted to the microcontroller system 5 for calculation, which then issues corresponding commands to control the main circuit's on/off state through electromagnetic mechanism 6.

According to the heat balance principle (also known as the law of energy conservation) [15], we have:

$$pdt = cGd\tau + kF\tau dt$$

where p is constant thermal power; c is the specific heat capacity of the heating element; G is the mass of the heating element; F is the heat dissipation surface area of the heating element; k is the heat dissipation coefficient; and τ is the temperature difference between the heating element and the cooling body at a given moment. In this paper, the temperature difference between the heating element and cooling body represents the temperature difference between the thermal relay's bimetallic strip and the internal environment of the thermal relay.

The first term on the right side of equation (1) represents the heat energy absorbed when the heating element's temperature rise increases by $d\tau$; the second term represents the heat energy dissipated to the cooling body while the heating element stores thermal energy. The constant thermal power is caused by resistance heating, thus:

$$i^2 R dt = cGd\tau + kF\tau dt$$

Dividing both sides by dt yields:

$$i^2R = cG \frac{d\tau}{dt} + kF\tau$$

Assuming the resistance of the thermal relay's bimetallic strip remains constant, and assuming the thermal relay's operating environment is stable, we can derive the relationship between current and temperature rise. If coefficients can be determined, the relationship between line current and heating element temperature rise can be described, enabling the thermo-electric hybrid overload protection control system to obtain line current by measuring temperature changes of the bimetallic strip and ambient temperature.

2.2 Theoretical Analysis

This paper proposes a new principle of thermo-electric hybrid overload protection, which is a simple and effective method. Combined with microcontroller control, it can achieve diverse protection characteristics with convenient adjustment, be unaffected by ambient temperature, provide good repeatability and stability, and facilitate intelligent control. Simultaneously, it can reduce the volume of electrical equipment, avoid iron core saturation at high currents, and expand the current monitoring range. Additionally, it can solve the problem of traditional thermal relays requiring waiting time for reset after operation.

3 Structural Design of the New Thermal Relay

This paper uses the JR36-20 thermal relay as a reference to redesign its structure into a new thermo-electric hybrid thermal relay. The JR36-20 is a three-phase bimetallic strip type with a tripping class of 10A and continuously adjustable current setting devices. Since the bimetallic strips of the JR36-20 thermal relay serve as the heating elements for the new thermo-electric hybrid thermal relay, as shown in Figure 2 [Figure 2: see original paper], heat-resistant insulating objects are used to fix the bimetallic strips to prevent them from bending when heated. Temperature sensors must quickly respond to line current changes; therefore, the insulating material should be thermally conductive, non-conductive, and capable of adhering to temperature sensors. This project selects 3J thermal conductive double-sided adhesive tape. Temperature sensors and temperature compensation sensors use PT100 thermal resistors. Temperature sensors for detecting the temperature of phases A, B, and C are attached to the three bimetallic strips of the thermal relay using thermal conductive double-sided adhesive tape, while the temperature compensation sensor for detecting ambient temperature is attached to the plastic housing of the thermal relay using the same tape.

4 Hardware Circuit Design

4.1 Overall Hardware Circuit Design Scheme

The hardware circuit of the new thermo-electric hybrid overload protection relay is shown in Figure 3 [Figure 3: see original paper], which includes a bridge measurement circuit, analog switch, differential amplifier, microcontroller, LED display, keyboard input, and relay output. PT100 converts the temperature signal of the bimetallic strip into a resistance signal, which is then converted into a voltage signal by the bridge measurement circuit. The analog switch selects the signal, which passes through the differential amplifier to the microcontroller. Inside the microcontroller, A/D conversion is performed, and after judgment and processing, the output signal is sent to the LCD display to show current values, temperature values, and the thermal relay's operating status and fault type, while simultaneously controlling the relay's on/off state. The keyboard input is used to reset the relay.

4.2 Hardware Circuit

Figure 4 [Figure 4: see original paper] shows the hardware circuit designed according to the overall hardware circuit design scheme and the design philosophy of this project. In the hardware circuit of Figure 4, the 74HC4051 is an 8-to-1 analog switch. Channels 0, 1, and 2 correspond to the voltage signals of PT100 on the bimetallic strips, channel 3 corresponds to the voltage signal of PT100 for measuring ambient temperature, channels 4 and 5 are used to adjust the amplifier's gain, and channel 6 is used for amplifier zero adjustment. The actual hardware circuit is shown in Figure 5 [Figure 5: see original paper].

5 Software Design

The software is designed according to the overload characteristic standards of thermal relays, combined with the mathematical model between overload current and temperature rise and the requirements for overload delay characteristics, implemented through the microcontroller. The program flow chart is shown in Figure 6 [Figure 6: see original paper].

This project can achieve current thermal overload protection, phase-loss protection, and current asymmetry protection based on current overload conditions. First, because the motor current increases rapidly during startup, it is necessary to avoid the motor startup process. In the program flow chart, a delay wait is used to handle this. Second, regardless of the type of fault based on current, the current value must be known. The project uses PT100 thermal resistors to measure the stable resistance values of each branch PT100 through the bridge circuit, then obtains the temperature rise by checking its division table, and subsequently obtains the current conditions of the three branches through the relationship between the main circuit current and temperature rise. Based on the relationship between current and the thermal relay's rated current, it can be

determined whether there is a current fault in the line and what type of current fault it is. If no fault exists, the program returns to the initialization position and continues to detect the main circuit current. If a fault occurs, different faults require different handling:

- (1) When an overload fault occurs, delay processing is required first. After the delay time expires, the overload fault is displayed and the relay performs tripping.
- (2) When a phase-loss fault occurs, the phase-loss fault is displayed and the relay performs tripping.
- (3) When an asymmetry fault occurs, the asymmetry fault is displayed and the relay performs tripping.

When fault handling is completed, the thermal relay requires manual keypress reset. After reset, it returns to the initialization position.

6 Experiments

Through the above theoretical analysis and design, the most critical aspect is to establish the mathematical model between the main circuit current and temperature rise through experiments. This paper collects the voltage across PT100 through a virtual server. At a certain ambient temperature, a specific current I_1 is applied to the thermal relay, and the change in hardware circuit voltage is observed. This yields the relationship between the voltage across PT100 on the bimetallic strip and the energization time at this current, as well as the voltage across PT100 representing ambient temperature. Since voltage and resistance have a linear relationship, and PT100 resistance and temperature also have a linear relationship, equation (7) can also be expressed as:

$$i^2 = A + B\tau$$

where u is the voltage across PT100 directly collected by the virtual server; A is a parameter related to the linear relationship between the heating element's specific heat capacity, mass, resistance, bridge measurement circuit resistance, and PT100 temperature resistance; and B is a parameter related to the linear relationship between the heating element's heat dissipation area, heat dissipation coefficient, resistance, bridge measurement circuit resistance, and PT100 temperature resistance.

In summary, the main circuit current can be obtained through equation (8) using measured experimental data. The experiment site is shown in Figure 7 [Figure 7: see original paper]. Considering the experimental capacity, the line rated current is selected as 3A. Each group of experiments collects 600 data points through the virtual server. The obtained voltages are shown in Figure 8 [Figure 8: see original paper], representing 2x overload (6A), 3x overload (9A), 4x overload (12A), and 5x overload (15A) respectively, showing the voltage signal changes of

PT100 corresponding to each overload condition and the corresponding voltage differences.

Analyzing the data in Figure 8 [Figure 8: see original paper] using Matlab software yields the model:

$$i^2 = 42.23 + 3710u + 1276u^2$$

Based on equation (9), the design of the new thermal relay that determines line current through temperature changes can be completed using the above hardware circuit and software program design. The experimental data are shown in the table below.

[TABLE:N] Comparison of actual current and display current

The table shows that there are differences between the current displayed by the hardware circuit and the actual current flowing in the line. As can also be seen from Figure 7, the voltage fluctuates. The reasons for this phenomenon are analyzed as follows:

- (1) The resistance of the bimetallic strip is not constant but changes with temperature increase.
- (2) The heat dissipation coefficient may vary with certain factors.
- (3) The verification of the new principle is based on modifications to the traditional thermal relay structure, whose heat dissipation conditions are poor, making it difficult to achieve thermal equilibrium.
- (4) During the experiment, since current changes are adjusted through a voltage regulator as a continuous variable, this may also affect some data parameters.

Despite some errors, this experiment verifies the feasibility of the new principle. Therefore, to apply this new concept in practice, the thermal relay structure needs to be redesigned. First, according to the system structure diagram in this paper (see Figure 1), heating elements should replace bimetallic strips, requiring the heating element's resistance to change little with temperature. Second, the thermal relay's heat dissipation conditions also need corresponding modifications. Solution one is to increase ventilation openings to improve heat dissipation capacity. Solution two is to replace the housing near the heating element with metal that has good thermal conductivity. Comparing the two solutions, solution one introduces new problems: if ventilation openings are added, the internal environment is no longer closed and becomes susceptible to external environmental influences. Solution two maintains a closed environment where heat dissipation is primarily achieved through thermal conduction, making the heat dissipation coefficient relatively constant.

7 Conclusion

This paper proposes a new design principle for thermal relays as motor overload protection. It can achieve multiple protection characteristics while ensuring compact size and providing intelligent display and alarm functions, combining the advantages of traditional thermal relays and electronic thermal relays, and is suitable for overload protection of all motors. The paper not only presents theoretical analysis, hardware circuit design, and software design for the new thermal relay but also modifies traditional thermal relays and verifies the feasibility of the new thermal relay through experiments. The structural parameters of the new thermal relay require further research. In summary, thermo-electric hybrid overload protection, as a new concept, can be applied not only to thermal relays but also to overload protection of circuit breakers and even short-time delay protection, which will promote the development of intelligent electrical apparatus.

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Note: Figure translations are in progress. See original paper for figures.

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