Modular substation intelligent control cabinet temperature control system

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Abstract—When the temperature control system of intelligent control cabinet of modular substation is designed by the current method, the PID controller is not improved, and there are problems such as low temperature prediction accuracy, low temperature tracking accuracy and poor control effect. The design method of temperature control system of intelligent control cabinet of modular substation is proposed. Through FPGA, input circuit, output circuit, man-machine interface, frequency division module five parts constitute the modular substation intelligent control cabinet temperature control system framework, in the temperature control system combined with the predictive function control algorithm to achieve the modular substation intelligent control cabinet temperature control system software system design. The experimental results show that the designed system can control the terminal temperature stably and reduce the temperature fluctuation to a small extent.

1. Introduction
Temperature measurement and temperature control play important roles in daily industrial production and life. Temperature control system is a new type of high-tech technology, which has gradually developed in recent years. With the diversity and universality of temperature controller applications, various temperature controllers emerge as the times demand [1]. Intelligent temperature control system has become a development trend in the information age. The main transformer is the core component in the operation of substation, and the reliability of temperature control system will directly affect the safe operation of substation [2]. To measure the accuracy of the temperature control system of the main transformer, there must be a perfect temperature system preventive experiment and experimental scheme [3-4]. There are two types of substation temperature control: oil level thermometer and winding thermometer. The oil level of the thermometer directly measures the oil temperature. The winding thermometer consists of a two-level superposition of the temperature thermometer and the load current of the substation under the action of elasticity. Yuan is a thermal simulation method for indirect measurement of winding temperature. The winding temperature is equal to the oil surface temperature plus the temperature rise. Reference [5] put forward the design method of temperature control system based on PID algorithm, the method through the
feedforward decoupling control interface zones that exist in the heating furnace heating channel, PID control algorithm was used to optimize existing in the temperature control system of control parameters, to complete the design of the temperature control system, the method is not improved PID control algorithm in the process of control. There is a problem of low accuracy of temperature prediction. Reference [6] the article puts forward the design method of the temperature control system based on ARM, the method using the constant current source temperature measurement circuit measuring modular intelligent temperature control cabinet, transformer substation by AD conversion takes the temperature of the signals to the control chip, on the basis of solid state relay control on-off heating tube in the control chip, adopts frequency converter to control the fan, realize the temperature control. The controller structure of this method is relatively simple, so it can't track the temperature accurately, and the temperature tracking accuracy is low. In order to solve the problems in the above methods, the temperature control system of modular substation intelligent control cabinet is proposed.

2. Design of temperature control system for intelligent control cabinet of modular substation

The temperature control system of the main transformer is composed of the temperature control system and the temperature measurement system. The temperature measurement system is composed of the local instrument and the remote measurement and display system. The local instrument is mainly the temperature controller of the substation. Substation temperature controller is composed of probe, PT100, temperature transmitter, elastic indicator, micro switch and other important components. The working principle of substation temperature measuring device is shown in Figure 1.

![Figure 1 Working diagram of temperature measuring device](image)

Modular substation intelligent control cabinet temperature control system design method frame is shown in Figure 2.

![Figure 2 Modular substation intelligent control cabinet temperature control system frame diagram](image)
As can be seen from Figure 2, the controller is the core part of the temperature control system of the modular substation intelligent control cabinet, and the controller is realized by FPGA chip.

2.1. Substation intelligent control cabinet temperature control hardware system

2.1.1. Configuration of FPGA

(1) Active serial configuration. In this mode, the program is first downloaded on the configuration chip, and the configuration operation is guided by FPGA [7]. FPGA usually plays an active role in the system. After the FPGA is powered on, it does not need the control of the controller or external computer, and the FPGA configuration chip EFCS is guided to load on the FPGA for the stored program. Solve the problem that the program is easy to lose after power outage.

(2) FPGA passive configuration. Generally, FPGA passive configuration is realized by controller or external computer, but this configuration mode has high circuit load and high cost.

(3) JTAG configuration. The JTAG configuration is usually divided into two categories, one is to test the electrical characteristics of the chip, and the other is to debug the program. JTAG mode can be used when the active serial configuration mode is selected during debugging. After debugging, the active serial configuration mode is applied in the program curing process. According to the above analysis, the temperature control system of modular substation intelligent control cabinet adopts the configuration mode of coexistence of JTAG mode and active serial configuration mode.

2.1.2. Input circuit

(1) Temperature sensors. In the process of designing the analog-digital converter, the circuit in the later processing is more complex, and there are problems of low measurement accuracy and poor reliability, which increases the wiring length of the temperature sensor and also increases the workload and production cost [8]. In order to improve the integration, precision and stability of the temperature control system of modular substation intelligent control cabinet, Digital temperature sensor DS18B20 is applied in the system design. The temperature resolution of DS18B20 is as high as 0.0625 degrees Celsius.

(2) Temperature measurement module. Modular substation intelligent control cabinet temperature control system design method through the DS18B20 temperature sensing, DS18B20 operation through the temperature measurement module control, to achieve the acquisition of temperature value. DS18G20 access process in the temperature measurement process is: initialization command, send ROM command code, send function command, DS18B20 design process is shown in Figure 3.

![Flow chart of DS18B20 temperature sensor design](image-url)

Figure 3 Flow chart of DS18B20 temperature sensor design
2.1.3. Output circuit
It usually includes two parts, namely the PWM module and the solid-state relay. (1) GJ10-W solid state relay. The temperature control of the intelligent control cabinet in modular substation can be realized by adjusting the input power of the heating furnace. Thyristor is usually used to adjust the temperature and control the power of the instrument, mainly through the following two ways: The first is the on-off control modulated power. Change the frequency of the voltage cycle in the control cycle to keep the voltage waveform stable. The second is phase control power modulation. (2) PWM module. PWM technology is a very effective technology which can control analog circuit by digital output of microprocessor. It has been widely concerned in many fields and has many advantages. The PWM controller based on FPGA has the advantages of field programming, high control precision, easy modification, simple structure, simple interface and adjustable switching frequency. It can realize multiplex PWM generator. PWM is mainly composed of comparator, memory or register and counter.

2.1.4. Frequency division module
Clock is the core of timing system in temperature control system of modular substation intelligent control cabinet. Most of the peripheral devices in the drive FPGA need to be implemented in the low frequency mode. The main purpose of the divider module is to provide different frequency clock signals for different modules. 500KV main transformer temperature measuring instrument is generally pressure thermometer, the controller is composed of elastic elements, temperature package, varistor, capillary connection pipe.

2.2. Temperature control software system for intelligent control cabinet of substation
The temperature control prediction model of modular substation intelligent control cabinet is composed of model function output and model free output. The control basis and composition basis of the model prediction algorithm is the prediction model, which mainly predicts the process output value of the software system at the future moment through the past state of the object and the input state of the software system. The expression of the prediction model is as follows:

\[ Y_m(n) = T_u(n) + F_n(n) \]  

(1)

In Formula (1), \( Y_m(n) \) represents the predicted output of the model at the moment \( n \); \( T_u(n) \) represents the output of the model under the action of the control quantity; \( F_n(n) \) stands for control action output. The reference trajectory of the temperature control software system of the modularized substation gradually stabilized intelligent control cabinet is usually selected as the first-order index:

\[ Y_j(k + t) = H(k) + \sum_{j=1}^{N_c} b_j(k) t^j - \theta^j [C(k) - Y_p(k)] \]  

(2)

In Formula (2), \( Y_j(k + t) \) represents the reference trajectory value corresponding to the moment \( k + t \); \( C(k) \) represents the set value of \( k \); \( N_c \) represents the number of polynomial expansion; \( b_j(k) \) represents the coefficients of the polynomial; \( t \) denotes time; \( \theta^j \) represents the attenuation coefficient corresponding to the set value of the system. \( Y_p(k) \) represents the actual output value of the process corresponding to the time \( k \). The dynamic characteristic function between the heating flow and the controlled temperature can be described by the following formula:
In Equation (3), $K_m$ represents the predicted gain; $T_m$ is the time constant; $T_d$ is the lag time.

The output of PFC-PID controller for temperature of intelligent control cabinet of modular substation at $k$ time is as follows:

$$u(k) = \frac{C(k) - G_m(S)}{K_m}$$  \hspace{1cm} (4)

The corresponding control quantity is obtained through the above formula, and the temperature control of the intelligent control cabinet in the modular substation is realized in the intelligent control cabinet temperature control system.

3. Experimental analysis

At the same time, according to the data of running shift and more than two years, there are two tables difference in C phase windings 2 of main transformer # 1. Through study, the experiment scheme is made, and the system problems are investigated one by one. The experiment flow is written by n files, and the transfer function needs to be discretized. Set 0.001 s as one step, the experiment time is 0.5s, and the 200th sampling moment is loaded with pulse to verify the system anti-disturbance. The experimental results show that the intelligent temperature control curve can fully show the ideal effect when the initial PID parameters are $a = 0.4$, $b = 0.0$, $c = 1.0$. The step response of the system in reference [5] and reference [6] are compared with that of the control system in this paper. Under this parameter, the experimental comparison results are shown in Figure 4.

It can be seen from Figure 5 that when the temperature control time is 0.05s, the sustained response time of the reference [5] system and the reference [6] system are 0.6s and 0.2s respectively, and the sustained response time of the system in this paper is 1.1s, and then the three systems have the longest sustained response time; when the temperature control time is 0.2s, the sustained response time of the reference [5]
system and the reference [6] system are 0.2s and 0.5s respectively, and the sustained response time of the system in this paper is 0.98s, and then the three systems have the longest sustained response time. Therefore, the temperature control of the intelligent control cabinet of the substation designed in this paper can prolong the continuous response time of the system and make the control process completed in sufficient time. Comparison between the set temperature and the measured temperature is shown in Table 1.

| Setting temperature (℃) | Measured temperature(℃) | Heating rate(℃/S) | Temperature control time(S) | Steady state deviation(℃) |
|-------------------------|--------------------------|-------------------|----------------------------|--------------------------|
| 60                      | 60/~60                   | 35/3              | 60                         | 0                        |
| 65                      | 65/~65                   | 40/5              | 60                         | 0                        |
| 70                      | 70/~71                   | 45/6              | 60                         | +1                       |
| 75                      | 75/~76                   | 50/8              | 60                         | +1                       |
| 80                      | 79/~81                   | 55/9              | 60                         | ±1                       |
| 85                      | 84/~86                   | 60/10             | 60                         | ±1                       |
| 90                      | 89/~91                   | 65/11             | 60                         | ±1                       |
| 95                      | 94/~96                   | 70/12             | 60                         | ±1                       |

According to Table 1, the temperature can reach the set temperature quickly. After entering the temperature control stage, the temperature is stabilized within ±1℃ of the set temperature, and there is no big fluctuation in the temperature control time.

4. Conclusion

The designed modular substation intelligent control cabinet temperature control system can make up for the problem of poor temperature control elasticity of the traditional temperature control system, and can stabilize the terminal temperature and reduce the temperature fluctuation to a small amount. In addition, the control system also has flexibility, which can realize automatic data acquisition and processing, thus providing an effective basis for temperature control, optimizing process operation, reducing production costs, and achieving effective production benefits. However, this article does not consider the influence of the external temperature environment on the temperature control of the transformer control cabinet, so in the future research, the external temperature will be considered as a factor to further improve the method in this article.

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