Study on an intelligent cooling control method of transformer

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Abstract. With the implementation of unattended and intelligent substation, the operation and maintenance personnel are far away from the substation. The cooling system lacks real-time monitoring, fault prediction, remote control and other functions. The number of transformer non-stop caused by cooler fault is further increased, which directly threatens the power grid security. In order to solve the above problems, a new intelligent air-cooling control method is proposed. Based on the large-scale signal acquisition method, a new intelligent air-cooling system design scheme is proposed. The characteristics, hardware system design, software system design, main program design, oil temperature control design, comprehensive switching design, data sharing center design message flow design and other key links of the new intelligent transformer cooler control system are introduced in detail. The results show that the scheme can better meet the needs of unattended substation and realize the intelligent operation of substation. It can further improve the security capacity of transformer production and play an important role in the construction and development of smart grid.

Keywords: Transformer, Cooling system, Signal acquisition, Intelligent control, Unattended.

1. Introduction
Transformer is the most basic and important equipment in power system. There will be loss during the operation of the transformer. The heat energy emitted by the transformer will make the temperature of the winding, iron core and oil rise. Too high temperature of transformer will seriously affect its load capacity. At the same time, it will accelerate the aging of insulation materials used in transformer winding and iron core, affect its service life, and even cause safety accidents [1-2]. In order to ensure the safe, stable and economic operation of the transformer, the oil temperature of the transformer should be detected at any time, and should be controlled in a fixed range by the cooler group all the time [3-8]. The existing air-cooling system is generally relay type or PLC type with many devices, complex wiring and difficult construction. Moreover, Regular inspection by operation and maintenance personnel is
required because of its poor reliability. Due to its poor protection function and low degree of intelligence, it is impossible to monitor the operation of the air-cooling system comprehensively [9-12]. In order to overcome these shortcomings, this paper puts forward a new design scheme, which is simple wiring, convenient construction and maintenance, operation and maintenance personnel can remote monitor, greatly reduce the inspection times of operation and maintenance personnel. In case of failure, operation and maintenance personnel can operate the local interface for troubleshooting and maintenance. The scheme with high reliability can carry out complex air-cooled motor protection function and realize automatic cooler balanced operation and fault switching.

2. Introduction of the transformer cooler system

2.1. Composition of the transformer cooler system

The transformer cooler system is mainly composed of circulating oil pump and air circulating fan. Based on the modular design, it meets the requirements of plug-and-play. In addition, it supports on-demand expansion, and facilitates the rapid integration of new application modules or subsystems. After the transformer is put into operation, the oil pump and fan operate based on the starting conditions such as oil temperature and load current. When the set value is reached, the intelligent cooler is put into the fan step by step to make the radiator full of transformer oil dissipate heat through forced air circulation. At the same time, the oil pump is put into operation step by step to make the transformer oil forced circulation, so as to achieve the effect of transformer heat dissipation. The disadvantages of traditional cooler are complex control circuit, low integration, poor control accuracy of temperature sensor and load current sensor, lack of intelligent interface, and difficult to realize remote monitoring [13-16].

On the one hand, the new intelligent cooler system proposed in this paper can collect, analyze and process the information of transformer oil temperature, load and cooler operation status, and control the operation and shutdown of the cooler according to the oil temperature and load, so as to maintain the oil temperature in a fixed range. On the other hand, the system has a complete motor protection algorithm, which can support 8 groups of coolers and 16 motors at the same time. Each motor protection can support at least 5 kinds of over-current curve setting. After the motor fault, the device can automatically generate waveform file and record the whole fault process. In addition, it also has the power supply automatic switching algorithm to realize the automatic switching function of I and II sections power supply. At the same time, it can automatically generate the waveform file when in the automatic switching action to record the whole fault process. The monitoring information and its analysis results can be locally displayed in an intuitive and visual way, and sent to the monitoring center in time. The new intelligent cooler system is the technical guarantee for the reliable, safe and economic operation of transformer, and the supporting equipment for professionals to intelligently judge and evaluate the operation status of transformer and cooler.

2.2. Features of intelligent cooler control system

2.2.1. Large-scale high-speed signal acquisition. The intelligent cooler control system has 66 channels of AD sampling, 33 channels of DI sampling and 22 channels of output, respectively corresponding to four external signals: transformer operation condition (oil temperature and load current), each group of cooler operation condition (fan, oil pump current and corresponding switch position), incoming power operation condition (power supply current, voltage and bus voltage, etc.), control cabinet internal operation environment (temperature and humidity).

2.2.2. Motor protection control. The motor control and protection unit adopt high-performance microprocessor that has rich AD sampling channels, serial interface and complete motor protection algorithm. It can sample the three-phase current signals of cooler fan motor and oil pump motor and the position signals of cooler circuit breaker contactor at high speed for comprehensive calculation and analysis. Then, signals sampled would compare with the motor protection setting value to realize the
motor protection of start-up, quick break, phase loss, short circuit, locked rotor and three-phase unbalance.

2.2.3. **Automatic switching of power supply.** The automatic switching unit adopts high-performance ARM processor with abundant AD sampling channels, SPI bus interface and serial interface. With power supply automatic switching algorithm, it can monitor the working state of incoming power supply in real time, and realize the automatic switching function of I and II power supply. The automatic switching unit also has a nonvolatile memory device, which can record and save all the sampling signals at the time of power failure for later accident recall and fault analysis.

2.2.4. **Switching of intelligent cooler unit.** The intelligent cooler unit can be switched according to winding temperature, top oil temperature or both of them. The intelligent cooler unit has the control strategy of switching on and off temperature threshold with temperature difference margin, which can automatically adjust the operation state of the cooler online according to the current operation time and accumulated operation time. It can cut off the cooler with the longest running time at present, and put into operation the cooler with the shortest accumulated running time, so as to achieve the balanced work of the cooler.

2.2.5. **Local display.** It can display the operating conditions (voltage, current, switch position and equipment fault) of the cooling system with animation graphics, display the current working status (operation, standby, maintenance, fault), current operating time, cumulative operating time, oil flow node and other status information of the cooler in real time, and display the current ambient temperature, humidity, the top oil temperature and winding temperature of transformer in real time.

2.2.6. **Remote communication.** It can simultaneously support the communication with three external systems using different communication protocols, support the real-time sampling data, fault recording data, configuration parameters sending, support the remote switching of cooler and setting of cooler maintenance signs, support the remote modification of device parameters and setting of devices working mode.

3. **Hardware and software structure of intelligent cooler control system**

3.1. **Hardware structure of intelligent cooler control system**

The newly developed device is a new generation of transformer cooler intelligent control device which integrates motor protection and control, power supply automatic switching and cooler intelligent switching. Therefore, the hardware design follows the principle of "function independence and board card separation". The whole system adopts "back plug structure and rail installation". Each intelligent control board realizes information exchange and control through backplane bus.

As shown in Fig. 1, the internal hardware structure adopts 8 motor protection control boards to realize the operation condition monitoring and protection control of 8 groups of coolers respectively. Each motor protection control board has a complete motor protection algorithm, which can monitor the current signals of the fan and submersible pump motor of the cooler in real time, realize the functions of start-up, quick break, phase loss, short circuit, locked rotor, three phase unbalance protection etc., and record the waveform information completely. The power supply automatic switch board can monitor the state of power supply and bus voltage in I and II sections of incoming line, automatically switch the power supply in case of power failure, so as to realize the complete power supply automatic switch function, and record the whole fault process. The integrated switching control board realizes the corresponding switching strategy according to the collected oil temperature, and realizes the automatic switching of the cooler, so as to keep the oil temperature of the transformer in a reasonable range. The on-site LCD control panel can display the operating conditions of the transformer and cooler on site, and help the operation, maintenance and dispatching personnel to monitor, control and judge the fault
nature and action behavior of the air-cooling system. The remote communication module transmits the collected information and the analysis results to the remote-control center through RS485 or Ethernet bus to realize remote online monitoring and control.

![Internal hardware structure of the intelligent cooler control system](image1)

**Figure 1.** Internal hardware structure of the intelligent cooler control system

3.2. *Software structure of intelligent cooler control system*

The specific control system software structure is shown in Fig. 2.

![Internal software structure of the intelligent cooler control system](image2)

**Figure 2.** Internal software structure of the intelligent cooler control system
4. Design of transformer intelligent cooler control system

4.1. Main program design of control system

The main program of the control system includes power on self-test, initialization, start-up and monitoring the working condition of each subtask. When the subtask is abnormal, it can record the abnormal information and reset the subtask. Each subtask runs independently and works in coordination. The external information sampling control subtasks (transformer information sampling task, external environment sampling task, power supply automatic switching sub task, and motor protection sub task) collect the oil temperature, current, voltage and node signals of each external circuit respectively, and carry out intelligent diagnosis of equipment status. After the fault is found, the fault equipment is recorded, alarmed and removed. The intelligent switching subtask is used to comprehensively judge the oil temperature control strategy, and the cooler is switched on or off according to the specific situation of the oil temperature, so as to keep the oil temperature in a constant range. The main program flow is shown in Fig. 3.

![Flow chart of the main program](image)

Figure 3. Flow chart of the main program

4.2. Transformer oil temperature automatic control design

As shown in Fig. 4, in the automatic control scheme, the control device takes the top oil temperature of the transformer as the controlled quantity. The microcomputer controller is used as the controller, the solid-state relay as the actuator, the air-cooling device as the controlled object, and the temperature controller as the transmitter. The transformer load, winding temperature and ambient temperature that cause the transformer oil temperature change are regarded as the external disturbance of the control system. The working process of the transformer oil temperature automatic control system is as follows. The change of transformer load or ambient temperature will lead to the change of transformer oil temperature that is sent to the microcomputer controller through the signal collected by the temperature sensor. The microcomputer controller generates the control decision to control the switching of the air-cooling device according to a certain control strategy. The control decision realizes the switching of the air-cooling device through the solid-state relay and controls the oil temperature of transformer through switching the air-cooling device.
4.3. Integrated switching control design

In the automatic control system of transformer oil temperature, according to the switching temperature threshold with delay margin, the comprehensive switching control decision is made. According to the cumulative operation time and cumulative stop time, the specific switching of a group of air-cooling devices is made. The working process is shown in Fig. 5.

4.4. Design of data sharing center

Data sharing center is an efficient and fast channel for information sharing among various modules of the whole system. Each module can interact and access a large amount of data through the data sharing center. For the data storage category, it can store the static data of the system model, including the configuration information of system setting value, input, output, etc. The dynamic data of oil temperature, cooler state quantity and effective value of electrical quantity can be stored. It also has concurrent access function, which enables multiple task modules to access shared data safely and concurrently. The data sharing center is realized by Linux kernel shared memory technology. It has the
function of data update, which can make each task module update and share data safely. The implementation of shared memory exists in the form of common files for all modules in the system.

4.5. Message flow design

4.5.1. Static model data. The model data is read by the external communication module and updated to the data sharing center by the system model data.

4.5.2. Dynamic state data. The external information acquisition module collects the external input and AD signals, and updates the collected results to the data sharing center. The intelligent logic judgment module extracts the sampling data from the data sharing center, analyzes and compares it with the configuration setting value, so as to obtain the operation condition and current switching operation of the cooler. If switching operation is needed, the acquisition control module is called to realize intelligent switching, and the analysis results are sent to the external communication control module through the message queue. Then the external communication control module distributes the data to the LCD module and the remote background communication module. Of course, the external communication module can also directly access the data sharing center and distribute the current measurement information to the LCD module and the remote background communication module.

4.5.3. External control command. As shown in Fig. 6, when the cooler is manually switched on or off through the human-computer interface, the external communication module sends the commands received to the intelligent logic judgment module. The intelligent logic judgment module analyzes whether the working state of the current cooler meets the switched on or off condition, and calls the acquisition control module to achieve the switched on or off operation. Then the input or cut operation will be returned to the external communication module. When the external data model is modified manually through the human-computer interface (such as constant value model data), the external communication module calls the data access module to modify the model configuration file and update the modified value to the data sharing center.

![Figure 6. Message flow design](image)
4.6. Intelligent logic judgment design

![Intelligent Logic Diagnosis Diagram](image)

**Figure 7.** Intelligent logic diagnosis task

According to the static model data of the data sharing center, the real-time running state data of the cooler, the oil temperature and load data of the transformer and other information, the comprehensive intelligent diagnosis is carried out to judge the working state of the cooler and to carry out intelligent switching on and off. The task flow of intelligent logic diagnosis is shown in Fig. 7.

5. Conclusion

The design method of transformer intelligent cooler control system can better meet the development needs of smart grid construction and the requirements of new substation integrated automation control. The scheme can improve the reliability and economy of transformer operation, better meet the needs of unattended substation, and realize the intelligent operation and interactive realization of substation.

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