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A New Type of Dehumidifier for Enclosed High-voltage Switchgear Cabinet

Jinbo Zhang*[1,2], Tongguang Shao[1,2], Yu Wang[1,2], Jing Wang[1,2]
[1]College of Computer & Information Engineering, Hohai University, Changzhou, China 213022
[2]Jiangsu Provincial Key Lab. of Power Transmission Equipment Technology Changzhou, China 213022
*corresponding author, e-mail: 1989stg@gmail.com

Abstract

In order to eliminate the internal condensation of enclosed switchgear cabinet, this paper introduced a subminiature and high-performance dehumidifier based on semiconductor refrigeration technology. This equipment utilized a Fuzzy self-tuning PID intelligent controller to monitor the humidity change in the cabinet continuously and judged the dehumidifier start-stop automatically. Besides, real-time communication with a host computer through RS485 interface was also considered. Experiments showed that this design could effectively reduce the internal humidity, eliminate the condensation, and provide a practical and effective solution to prevent the power device accidents caused by wet and condensation.

Keywords: *high-voltage switchgear, semiconductor refrigeration, condensation, dehumidifier*

1. Introduction

In the power system, the insulation conditions of power transmission and transformation equipment are essential factors to the security of it, especially in the complex climate conditions. Due to wet and condensation, the degraded insulation performance initiates operational accidents easily, which brings about serious economic loss to society. Thus how to solve the problem of wet and condensation is a significant issue to ensure the security of power equipment.

In switchgear cabinet, control cabinet, terminal box and other power equipment, the traditional methods to prevent the wet and condensation are heating and exhausting air, which generally functions well. Given the high humidity in the enclosed cabinet, the traditional ways face some limitations. Compared with these traditional methods, semiconductor refrigeration has many advantages, such as no moving parts, high reliability, long life, compact volume, easy to control, capable to achieve high temperature difference, green and non-pollution [1]. Therefore, it is necessary and important to develop and research a new type of dehumidifier for enclosed high-voltage switchgear cabinet based on semiconductor refrigeration technology.

For enclosed cabinet, drops will generate on metal surface when the temperature of this metal surface decreases blew dew-point, this phenomenon is called condensation. Whether condensation will generate depends on several variable quantityies including ambient temperature, cabinet internal temperature, relative humidity, dew-point, etc. The main situations that make enclosed cabinet generate condensation easily are:

1. High humidity and changeful daily temperature. Drops may easily generate on metal surface when hot and cold air exchange.
2. The bottom of cabinet boy is wet and even there’s some water in cable channel. When water evaporates and the metal surface temperature is lower than the air temperature, condensation will generate.
3. Some devices are in the outage statue, cabinet internal temperature is often lower than the ambient temperature, so that condensation will also generate. Once these devices are put into use in this condition, accidents may easily occur, such as creepage and flashover phenomenon.

According to its formation mechanism, two conditions must be met before vapor condensation formation: high ambient relative humidity and ambient temperature variation, in which ambient relative humidity has the greatest influence. In order to prevent condensation, at

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least one of these two formation conditions must be broken. Both reducing the relative humidity and reducing the temperature difference could be taken as anti-condensation measures.

Currently, heating with heater and ventilating with fan are mainly taken to achieve anti-condensation inside the cabinet. But these two methods on cabinet anti-condensation are less effective in high humidity regions or seasons, numbers of accidents have occurred as a result of condensation. Heating method can only alleviate the cabinet internal condensation, it can't reduce the relative humidity in enclosed cabinet, and lots of water vapor in the cabinet is not discharged. Furthermore, prolonged heating not only consumes large amounts of energy but also leads to equipment aging and shortens the life of equipment. Consequently, relative humidity inside the cabinet must be reduced, so as to truly achieve the purpose of dehumidify and anti-condensation.

When a glass of water is taken out from refrigerator in summer, large amounts of drops will generate on its surface. This condensation phenomenon will go on forever as long as the temperature difference exists between the surface of this glass and the ambient air, and the moisture in ambient air will be absorbed continuously if the condensate is removed, this is the dehumidifier phenomenon or dehumidifier principle.

In general, commercially available dehumidifiers are made up of compressor, fan, condenser, refrigerant materials (F21 or other materials), etc. However, this kind of dehumidifier can only be used in a large space but not enclosed cabinet as a result of its volume and power consumption. Subminiature and high-performance dehumidifier developed with semiconductor refrigeration technology can make up for all the deficiencies of above methods.

2. Semiconductor Refrigeration

Semiconductor refrigeration (thermoelectric cooling) is a cross subject developed between refrigeration technology and semiconductor technology in 1950s, it uses the special semiconductor material to make up a P-N junction, which forms a thermocouple and refrigerates with direct current.

2.1. Principle of Semiconductor Refrigeration

Thermoelectric Cooler (TEC) is a kind of heat pump, it has no mechanical moving parts and can be used in certain situation where the space is limited, reliability requirements is strict and refrigerant pollution is not tolerated.

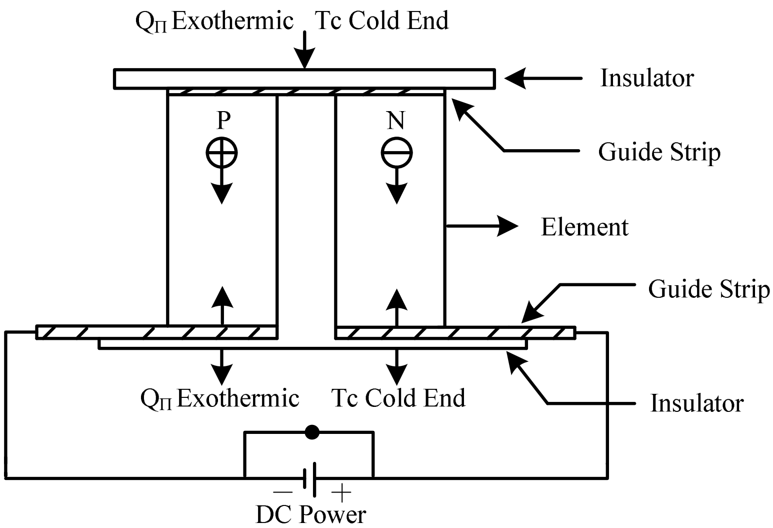

Figure 1. Schematic diagram of semiconductor Refrigeration

As shown in Fig.1, a single of refrigeration piece consists of two ceramic pieces made from N-type and P-type semiconductor material (Bi_2Te_3), this semiconductor component is connected with series form in the circuit.

When an N-type and a P-type semiconductor material connect into a galvanic couple pair, after being connected with direct current, energy transfer occurs. Current flows from N-type component to P-type component joint to absorb heat and become a cold end, current flows from P-type component to N-type component joint to release heat and become a hot end. The scale of endothermic and exothermic is determined by the value of current and the number of N, P components, hundreds couples of galvanic are connected into a thermopile in refrigeration piece in order to enhance the effect of cooling(heating).

Semiconductor refrigeration is developed on the foundation of thermoelectric effect, which consists of 5 different effects; they are Seebeck effect, Peltier effect, Thomson effect, Joule effect and Fourier effect. The Seebeck, Peltier and Thomson effect are reversible, while Joule and Fourier effect are irreversible. Although the semiconductor refrigeration is the interaction of these five effects, Peltier effect plays a major role in them.

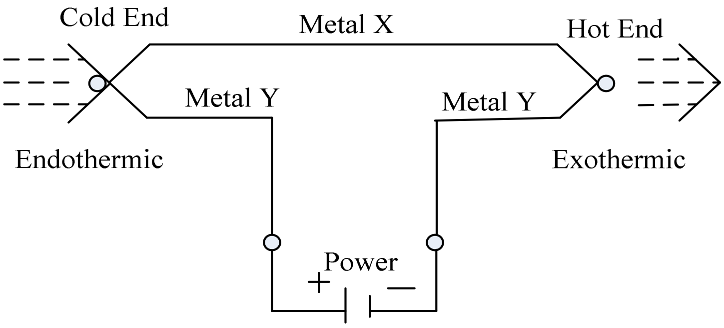

Figure 2. Schematic diagram of Peltier effect

In 1834, French physicist Peltier discovered that when direct current flows through the closed circuit composed by two different metals, the heat Q was absorbed on one joint, while the same amount of heat was released on the other joint. This kind of heat was named Peltier Heat, and the schematic diagram of it is shown in Figure 2.

The heat of the cold end is transferred to the hot end after connecting the power supply, and the temperature of cold end decreases while it increases in the hot end, this is the famous Peltier effect.

2.2. Fundamental Refrigeration Calculation

When a cooling device (a PN junction couple or single-stage thermoelectric chip) gets into thermal equilibrium under the action of current I, cold end temperature T_c, hot end temperature T_h and hot-cold ends temperature difference $\Delta\tau$, the corresponding driving voltage U, cooling capacity Q_c (sometimes can also be interpreted as cold load), electrical power N_0, cooling efficiency E_c can be represented as follows [2]:

$$Q_c = \alpha T_c I - I^2 R_0 / 2 - K\Delta\tau \quad (1)$$

$$N_0 = I^2 R_0 + \alpha \Delta\tau I \quad (2)$$

$$U = R_0 I + N_0 \quad (3)$$

$$E_c = Q_c / N_0 \quad (4)$$

Among them, α, R_0 and K are the cooling device's equivalent Seebeck coefficient, total equivalent resistance and equivalent thermal conductivity, respectively.

Defined Z as the thermoelectric material's figure of merit, the maximum cooling capacity current $I_{Q\max}$ and the maximum efficiency current $I_{E\max}$ can be computed as follows:

$$I_{Q\max} = \frac{\alpha}{R_0} T_c , Z = \frac{\alpha^2}{R_0 K} \quad (5)$$

$$I_{E\max} = \frac{\alpha}{R_0} \frac{\Delta\tau}{\left(\sqrt{1+0.5Z\left(2T_c+\Delta\tau\right)}-1\right)} \quad (6)$$

$$\Delta\tau_{\max} = \frac{1}{2} Z T_c^{\ 2} \quad (7)$$

I_{best} has two meanings: When T_c and T_h are fixed, it represents the maximum cooling capacity current $I_{Q,\max}$; when T_h and Q_c are fixed, it represents the maximum thermoelectric current $I_{\Delta\tau,\max}$. $\Delta\tau_{\max}$ is the thermoelectric current between the hot and cold ends while the working current is $I_{\Delta\tau,\max}$ in the condition that $Q_c = 0$ [3].

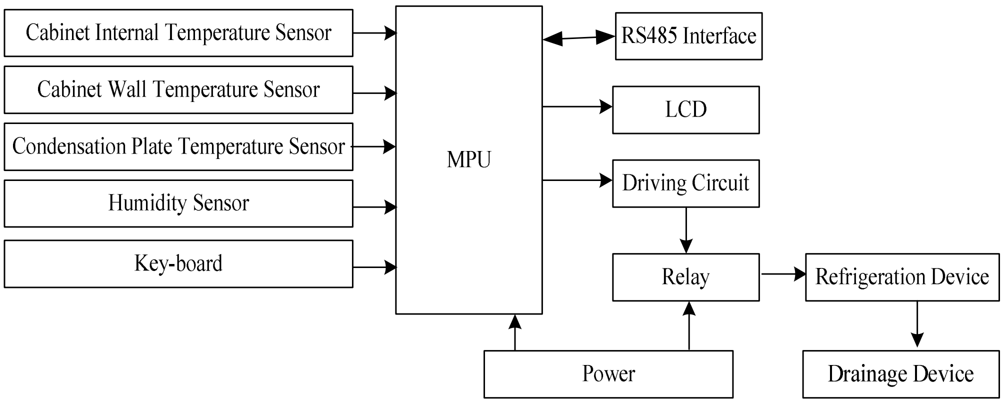

Figure 3. Schematic diagram of a dehumidifier

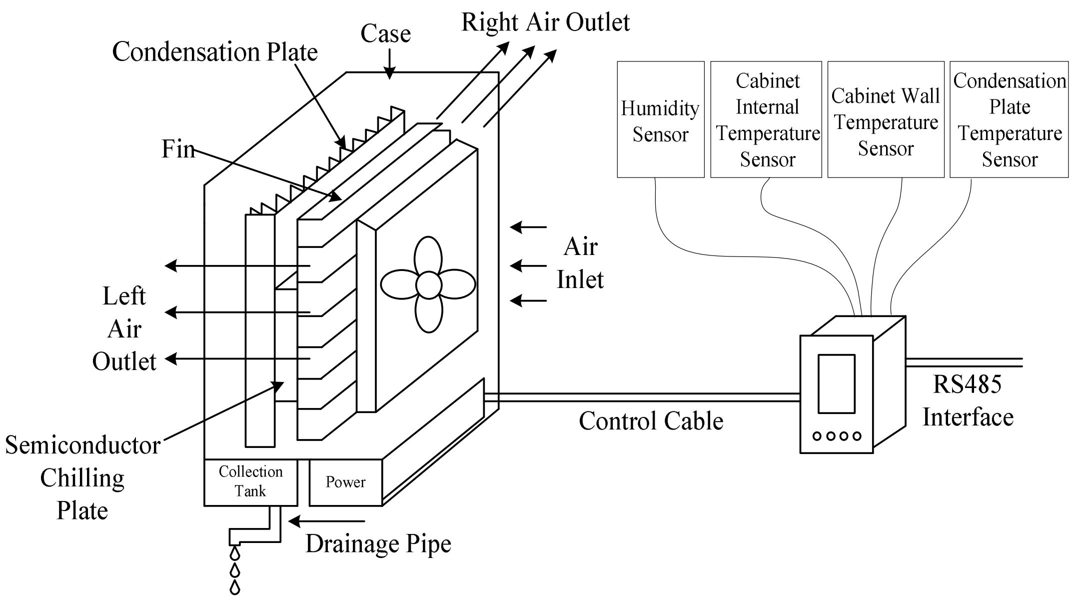

Figure 4. Dehumidifier structure design

3. Enclosed High-voltage Switchgear Cabinet Dehumidifier

A new type of dehumidifier applied to enclosed high-voltage switchgear cabinet is designed based on the theory above.

3.1. Dehumidifier's Hardware

The subminiature and high-performance enclosed high-voltage switchgear cabinet dehumidifier mainly consists of cabinet internal temperature sensor, cabinet wall temperature sensor, condensation plate temperature sensor, cabinet internal humidity sensor, microprocessor, RS485 interface, LCD, relay drive circuit, refrigeration device, drainage device, power supply, etc. The electrical block diagram of it is shown in Figure 3 and the integral structure of it is shown in Figure 4.

Cabinet internal temperature sensor, cabinet wall temperature sensor and condensation plate temperature sensor are respectively used for the measurement of the cabinet internal temperature, cabinet surface temperature and the condensation plate surface temperature. Cabinet internal humidity sensor, which uses a linear temperature sensor, is used for the measurement of the relative humidity inside the enclosed cabinet.

3.2. Dehumidifier's Software

Software design is an important part of the enclosed high-voltage switchgear cabinet dehumidifier. Its major task is to initialize the dehumidifier, receive commands from keys, obtain and process the data from different sensors, display parameters and states on LCD, communicate with the host computer and achieve the Fuzzy self-tuning PID control.

3.2.1. Control Flow

The main program of enclosed high-voltage switchgear cabinet dehumidifier consists of initialization module, key-press module, display module, etc. The collection of the temperature data, scale transformation and control algorithm are realized by its subprogram. Figure 5 shows the program flow chart.

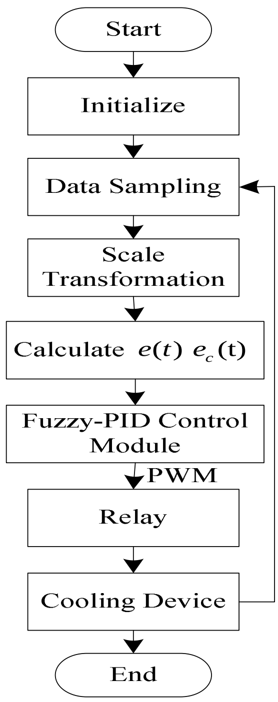

Figure 5. Algorithm flow chart

After obtaining the humidity information collected by the sensors, MPU calls the scale transformation module to calculate the feedback data, and the input is calculated based on the deviation $e(t)$ and the deviation variation rate $e_c(t)$, then output is produced by the Fuzzy self-tuning PID intelligent control algorithm. Then, the output will be converted to a PWM signal used to drive relays, and at last the controller achieves the control of refrigeration device.

3.2.2. Fuzzy self-tuning PID Intelligent Control Algorithm

PID control law is a fairly ideal, which introduces integration on the basis of proportion to eliminate the residual error, and differentiation can improve the system's stability [4]. It is suitable for the occasions with a large control channel time constant, capacity lag or high control requirement. The PID controller is calculated as follows:

$$u(t) = K_p \left[e(t) + \frac{1}{T_I} e(\tau) d\tau + T_D \frac{d(e(t))}{dt} \right] \tag{8}$$

In which, $e(t)$ is the system feedback deviation, K_p is the proportional coefficient, T_I is the integral time and T_D is the differential time.

Introducing fuzzy control algorithm to the traditional PID control system makes up a new Fuzzy self-tuning PID intelligent controller. The purpose of using this intelligent controller is to make the controller adjust PID parameters with fuzzy control algorithm on-line and adaptively according to the actual situation, so as to achieve the real-time optimal adjustment and make up the deficiencies of fuzzy controller and PID controller when they act alone and improve the overall control effect on system. The Fuzzy self-tuning PID intelligent controller's block diagram of enclosed high-voltage switchgear cabinet dehumidifier is shown in Figure 6.

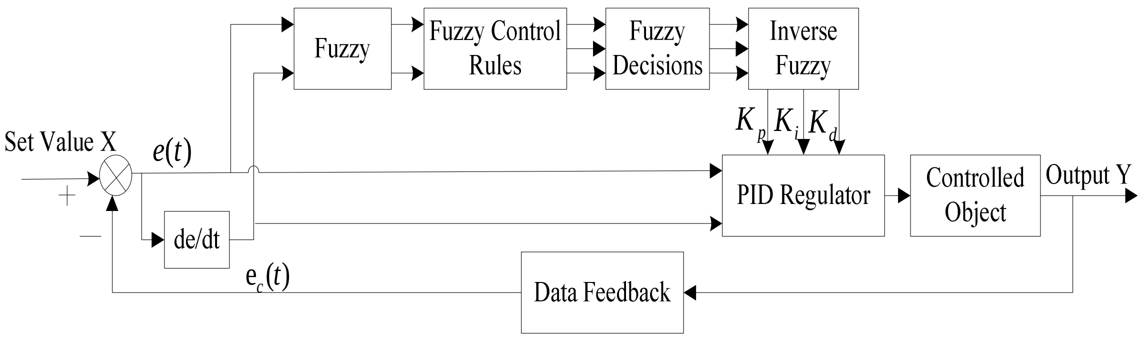

Figure 6. Fuzzy self-tuning PID intelligent controller

In the view of the dehumidifier's application effect, the Fuzzy self-tuning PID intelligent controller has the flowing features:

1. The system has good dynamic characteristics.
2. The system has an ideal steady quality, the steady process has no oscillation, and the humidity control precision is within ±1 $^\circ C$.
3. System's jamming-rejection capability is improved and has a good inhibition on the field interference
4. The control system can still maintain a good adaptability and robustness when the control process parameters changed.

4. Results and Analysis

For the purpose of proving the effect of this way on anti-condensation, following experiment was done.

Experimental environment: ambient temperature 10-20 $^\circ C$, humidity 40-70%. Semiconductor chilling plate selects TEC1-12712, working voltage 12V, working current 12A, theoretical power 144W. Use CPU radiator as the cold surface of chilling plate, and dissipate heat with 200W heater fan on the hot surface.

Experiment found that there is no condensation on chilling plate when the ambient humidity was below 40%, and when it was about 40%, condensation phenomenon appeared.

As a result of the refrigeration equipment's low cooling rate but high heating rate, the original heater part can be considered using the heat released from hot-side; the cold-side achieves condensation in cabinet and discharges water. If the cooling effect is too better to produce frost, stop the equipment five minutes every 3 hours to make it defrost in order to ensure the cooling effect. For relatively enclosed cabinet, internal temperature will be raised and at the same time the humidity will be reduced. In addition, the power supply of refrigeration equipment should be cut off when the temperature is over the pre-set upper limit.

5. Conclusion

Enclosed high-voltage switchgear cabinet dehumidifier is designed according to principle above. The humidity value could be preset by the keyboard of this equipment within the range of 30-90%. The refrigeration equipment is forced to turn on when the humidity is over the preset value, or the cabinet internal temperature is over $3^{\circ}C$ than the wall temperature while the internal humidity is over 40%. At present, most of the power grid application is working in natural environment, of which the climate is very complicated and variable. The electric power operation accidents and economic loss have reached a very amazing point as a result of insulation performance reducing caused by vapor condensation. Therefore, how to deal with moisture-proof and anti-condensation problem of electrical equipment is an important issue directly related to whether the power equipment can run safely. This paper provides a scientific and efficient method for improving the reliability and security of the power grid and completely avoid major accidents caused by vapor condensation.

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