An effect temperature measurement system for the high voltage pulse power switch application

Wei-bo LI, Wenjun TANG, Wang XIN, Yuxing ZHANG
National Key Laboratory for Vessel Integrated Power System Technology
Naval University of Engineering, Wuhan, China
E-mail: HUSTLWB@163.com

Shi-jia ZHAO
College of Electrical and Electronic Engineering
Huazhong University of Science and Technology
Wuhan, China
E-mail:zsj_china@hotmail.com

***Abstract*—How to thermostatic control and temperature monitor of the power electronics and its bank is very important to the healthy operation for the power converter. However, the work situation of the power electronics is high-level voltage, which will give bad influence to the temperature sensor head and its conditioning circuit. Some protection measures to the sensor head located in the high voltage level are necessary. An effective temperature test system used to detect the temperature of the heat bank of the pulse switch centered on thyristor is introduced. The integrated circuit temperature transducer AD590 has been proposed for the sensor head due to its simple use and its prompt availability. The sensor head is enclosed by an insulating box, which is casted by the silicone gel. And it is installed in the high voltage terminal of the current-carrying plate. The output signal reflected the temperature of the bank plate is transmitted by the twisted pair line with shielded cable. The test system can endure the high level voltage and be useful to the acquirement the operation state of the pulse power switch.**

Keywords- withstanding voltage; temperature transducer; insulating hull.

I. INTRODUCTION

The core of most power electronic apparatus consists of a converter using power semiconductor switching devices that works under the guidance of control electronics. Study indicates the thermostatic control and temperature monitor are very important to the healthy operation of the power plant. We take the pulse power switch centered on the thyristors (SCR's) as an example to introduce the thermal management for the plant, see reference [1].

For high energy short pulse discharge applications like high speed forming, mostly SCRs technology is used. ABB has developed a specific range of SCRs, and adapted standard products over the years, which can fulfill the requirements for pulsed applications. Some studies show the pulse power switches do key influences to the electromagnetic thrust force, power efficiency, and power quality. And at the present time, SCRs can be adopted as the pulse power switch for it can endure the high voltage and the surge current in short time, see reference [2].

The structure of the single-phase pulsed switches centered on the SCRs is illustrated in Figure1. The switch includes several important components, such as electrodes, SCRs (adopted as single-phase switches), heat bank, press plate and so on. But the RC snubber network is not shown in this Figure. It is advisable to use a shunt gate− cathode RC snubber across sensitive gate SCRs to provide a path for leakage currents and to insure that firing of the SCR causes turn-on of the trigger device and discharge of the gate circuit capacitor, see references [1, 3].

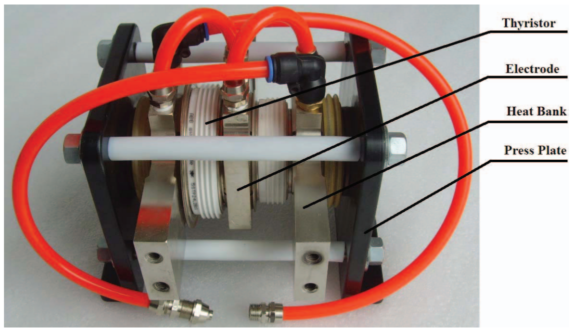


Figure 1. Photo of block witch centered on thyristors

The temperature transducer is arranged in the electrode bus. However, the electrodes are used to carry the heavy current and locate in the high-level voltage situation more than 5 kilovolts for the pulse switch plant. Therefore, the temperature transducer must be insulated to adapt the high level occasion according to standard more than 10 kilovolts level.

II. SOME DETAILS OF THE TEMPERATURE TEST SYSTEM

A. Temperature transducer

The integrated circuit temperature transducer, i.e. AD590, has been proposed for the thermostatic control and temperature monitor due to its simple use and its prompt availability. In the data sheets, its rated performance temperature range is stated from -55°C to 150°C, with a note that it can be extended to -100°C with some degradation of the performance, see references [4,5].

In this paper we investigate the behavior of this transducer at temperatures from -20°C to 130°C; the transducer has proved to work properly. For the task of testing the state of the heating unit of the thyristors pulse switch, the AD590 integrated-circuit temperature transducer has been proposed

Project Supported by National Natural Science Foundation of China (51077129).

because it is a calibrated two-terminal temperature sensor which requires only a dc voltage supply (ranging from +4V to +30 V), with a linear output current of 1 μ A/K. Transmitters, linearization circuits, precision voltage amplifiers, resistance measuring circuitry and cold junction compensation are not needed in applying the AD590, see reference [5].

The test circuit centered on AD590 sensor head is illustrated in the figure 2, where V_+/V is the supply voltage (+15V), V_M/V is the output voltage, and i_t/A/K is the output current.

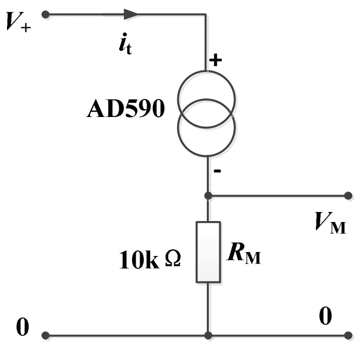


Figure 2. Test circuit centered on AD590 sensor head

And the output voltage, V_M, can be expressed as follows:

$$V_M = i_t \cdot R_M \cdot (T + 273.16) \qquad (1)$$

where, T is the measured temperature in °C degrees. And the output current, i_t/A/K, is the given value 1 μ A/K. An offset of 273.16 mV is required to have 0ºC as the reference temperature. The measurement resistance R_M is 10 kΩ. In other words, the output current from AD590 flows through resistance R_M, thereby developing a voltage of 10mV/ ºK. So the output voltage, V_M /mV, can be simplified as

$$V_M = 10T + 2731.6 \qquad (2)$$

Guessing dc reference voltage V_{ref} /mV can be defined as

$$V_{ref} = 2731.6 \qquad (3)$$

So the replacement expression of the output voltage, V_M /mV, can be shown as

$$V_M = 10T + V_{ref} \qquad (4)$$

Analysis of Eq. (4) indicates that the output voltage is proportional to the measured temperature T since the dc reference voltage, V_{ref} /mV, can be compensated by the OP amplifier circuit obtained from a voltage regulator.

B. Structure of the pulse switch centered on the thyristors

The equivalent circuit of the single-phase pulse switches are shown by figure 3, where two SCRs are connected in inverse parallel (the anode of each connected to the cathode of the other). The switches centered on two SCRs are designed to switch the bidirectional current.

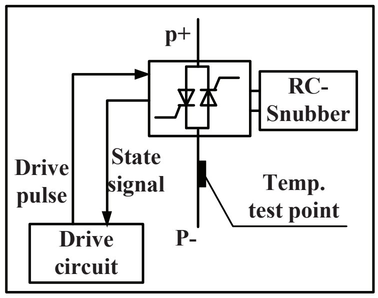


Figure 3. Equivalent circuit of the single-phase pulse switch

It is important to note that the SCR is a voltage controlling device. The load and power source determine the circuit current. First, some important attention must be attracted to the temperature state of the pulse switch centered on the SCR. The thermal losses of the SCR, are analyzed with the help of the 5STP52U5200 device produced by ABB co., see figure 4. And the AD590 sensor head is attached to the electrode bus, see figure 5.

Figure 4. Photo of 5STP52U5200 thyristor.

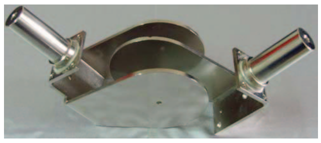


Figure 5. Photo of electrode bus.

C. Structure of the insulating shell for the sensor head

The structure of the insulating shell for the sensor head includes the enclosure fulfilled with silica gel; sensor head adopted by AD590; copper plate used as heat-conducting medium; and insulating substrate increasing insulate capability. And the whole shell can be explained by the figure 6.

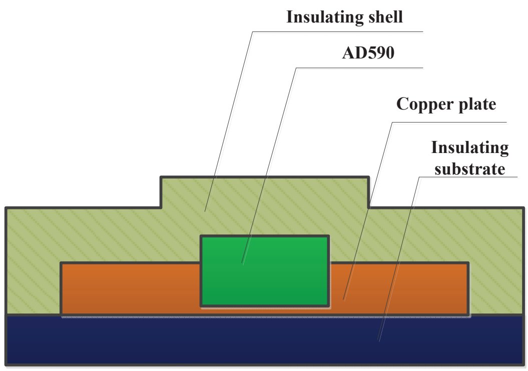
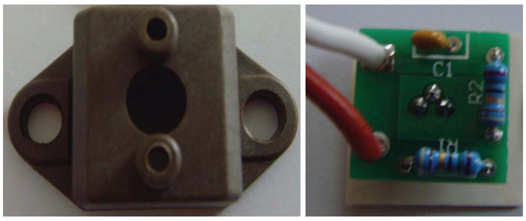


Figure 6. Structure of the insulating shell for the sensor head.

The Photo of the sensor head with insulating shell is plotted in figure 7, where figure (a) shows the insulating shell and (b) expresses the sensor head with the condition circuit.



(a) Insulating shell (b) Sensor head

Figure 7. Photo of the integrated sensor head.

D. Conditioning circuit

The output voltage, V_M /mV, can be computed by the two parts: $10T$ /mV and V_{ref} /mV, see Eq.(4) . When the offset constant, V_{ref} /mV, is compensated by the OP AMP conditioning circuit shown as figure 8, where four resistors, i.e., R_1, R_2, R_3 and R_4, are symmetry and given as R_1=R_3, and R_2=R_4. This offset is subtracted from the voltage across resistor and amplified by a third amplifier (A_3). So the output voltage reflected the temperature of the heat bank of the pulse switches, V_O /mV, can be computed by

$$V_O = 10T \frac{R_2}{R_1} \tag{5}$$

Analysis of Eq. (5) indicates that the output voltage, V_O /mV, is proportional to the tested temperature T.

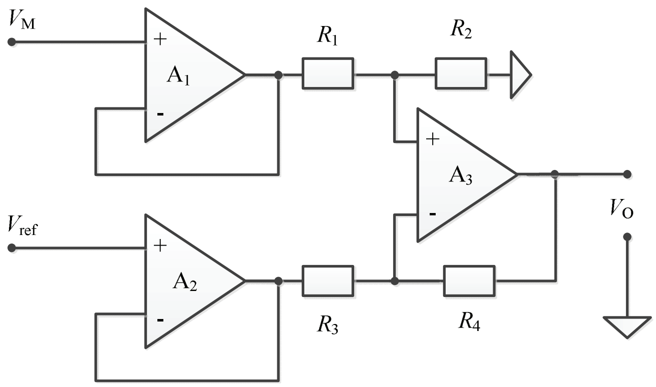


Figure 8. OP AMP conditioning circuit.

III. CMR OF OP AMP SUBTRACTION CIRCUIT

In order to be effective for the OP subtraction circuit, an in-amp needs to be able to amplify microvolt-level signals, while simultaneously rejecting volts of common mode signal at its inputs. This requires that in-amps have very high common mode rejection (CMR): typical values of CMR are 70dB to over 100dB, with CMR usually improving at higher gains.

It is important to note that a CMR specification for DC inputs alone is not sufficient in most practical applications. In industrial applications, the most common cause of external interference is pickup from the 50/60Hz AC power mains. Harmonics of the power mains frequency can also be troublesome. In differential measurements, this type of interference tends to be induced equally onto both in-amp inputs. The interfering signal therefore appears as a common mode signal to the in-amp. Specifying CMR over frequency is more important than specifying its DC value. Imbalance in the source impedance can degrade the CMR of some in-amps. Analog Devices fully specifies in-amp CMR at 50/60Hz with a source impedance imbalance of 1kohms. Low-frequency CMR of op amps, connected as subtraction circuit as shown in figure 9, generally is a function of the resistors around the circuit, not the op amp.

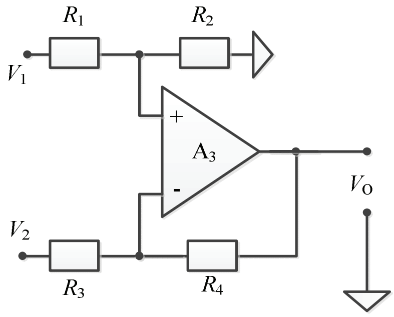


Figure 9. OP AMP subtraction circuit.

Research indicates that the critical for high CMR is mismatch of R_2/R_1 and R_4/R_3, when guessing

$$\frac{R_2}{R_1} = \frac{R_4}{R_3} \tag{6}$$

The output voltage, V_O /mV, can be computed by

$$V_O = (V_1 - V_2)\frac{R_2}{R_1} \tag{7}$$

The CMR is expressed by

$$CMR = 20\log_{10}\left(\frac{1+\frac{R_2}{R_1}}{k_R}\right) \tag{8}$$

where k_R is mismatch of the resistor ratios R_2/R_1 and R_4/R_3. A mismatch of only 0.1% in the resistor ratios, i.e., k_R =0.001, will reduce the DC CMR to approximately 66dB.

Another problem with the simple op amp subtraction circuit as shown in Figure 10 is that the input impedances, i.e., R_{S1} and R_{S2}, are relatively low and are unbalanced between the two sides.

Guessing

$$\begin{cases} R_1 + R_2 >> R_{S1} \\ R_3 + R_4 >> R_{S2} \end{cases} \tag{9}$$

and

$$\begin{cases} R_1 = R_3 \\ R_2 = R_4 \end{cases} \tag{10}$$

and

$$A_N = -\frac{R_4}{R_{S2} + R_3} \approx -\frac{R_4}{R_3} \tag{11}$$

and

$$A_P = \frac{R_2}{R_{S1} + R_2 + R_1}\left(1 + \frac{R_4}{R_{S2} + R_3}\right) \tag{12}$$

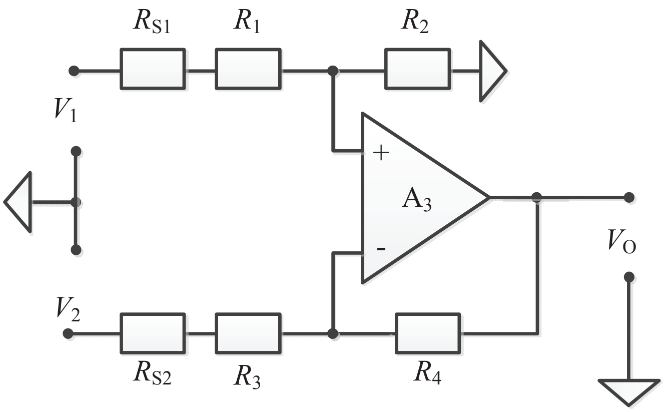


Figure 10. OP AMP subtraction circuit including source resistence.

The CMR is computed by

$$CMR = 20\log_{10}[(1 + A_N)k_S] \tag{13}$$

where k_S, the resistor ratio can be defined as

$$k_S = \frac{R_1}{|R_{S1} - R_{S2}|} \tag{14}$$

For OP AMP, an equation is effective as follows

$$|A_N| \approx \left|-\frac{R_4}{R_3}\right| >> 1 \tag{15}$$

Therefore, the CMR is also computed by

$$CMR = 20\log_{10}(A_N \cdot k_S) \tag{16}$$

A mismatch of only 1% in the resistor ratios, i.e., k_S =0.01, and A_N=100, will reduce the DC CMR to approximately 80dB. This configuration can be quite problematic in terms of CMR, since even a small source impedance imbalance will degrade the workable CMR.

For increasing the capability for CMR of the circuit, we must strictly control the error of the resistance of R_1, R_2, R_3, and R_4. The CMR of the OP AMP will be carefully selected.

IV. EXPEREMETAL RESLUTS

Some test data by the help of the AD590 temperature measurement system can be acquired in figure 11. The pulse switch cooled by water at the flow rate of 4s/min, conducts different current expressed as follows:

(1) Continuously conducting 12kA for 1.4s at 45s interval;

(2) Continuously conducting 15kA for 0.9s at 45s interval.

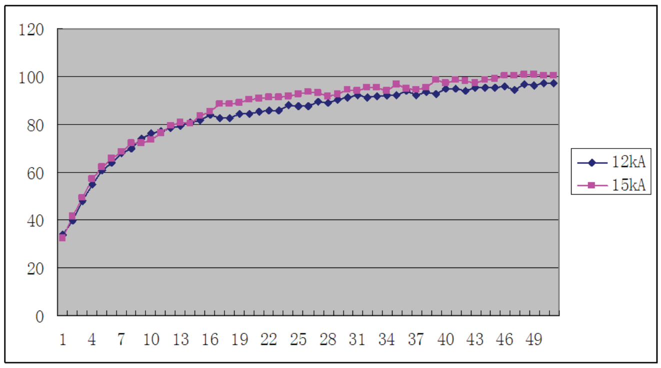


Figure 11. Temp curves of heat bank of pulse switch at different current.

Analysis of the temp curves shows the current peak is main factor determined the thermal losses of heat bank of pulse switch during conducting different current though the products of current square and time is same for two conditions, i.e., 12kA*12kA*1.4=15kA*15kA*0.9. The recycle index is more than 50 under the maximum temperature of the heat bank is less than 100 °C.

V. CONCLUSIONS

The performance of the insulating shell-based instrument is measuring temperature for the pulse switch heat bank, is investigated. The test plant can face more than 10 kilovolts high-level circumstance risk. The signal to mask ratio is so high that the test instrumentation can endure more than 100 meters distance from the test point. The range of the instrument is used to measure the temperature from -20°C to 130°C.The error in measurement is found to be less than 1%. In this instrument the manual supervision involved is little. The system is highly reliable, low cost, and portable.

REFERENCES

[1] Li Weibo, Rao Jin, He Hong, et. al, “Optimization and influence of the RC snubbers for the pulse power switch centered on the thyristor,” High Voltage Engineering,Vol.35, No.12, pp.3099-3105, 2009.

[2] Fu Peng, Gao Ge, Li Ding,et. Al. “The application of thyristor in high power converter and DC breaker,” Trans. of China electro technical society, Vol.19, No.8, pp.34-39, 2004.

[3] Lan Yuanliang, Tand Guang-fu, Yin Yong-hua,et.al, “Study on transient of reverse recovery of series thyristors,” Power System Technology, Vol.30, No.16, pp.15-19, 2006.

[4] Analog Devices “AD590 2-terminal IC temperature transducer”, data sheet, 2006, http://www.analog.com.

[5] A. Rajendran, P. Neelamegam, “Microcontroller based dielectric constant measurement,” Sensors & Transducers Magazine, Vol.41, No.3, pp.181 – 190, March 2004.