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Development of High-voltage Standard Current Transformer with Three Phases in One Enclosure Based on Shielding and Balanced Winding

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Abstract. When three-phase testing method is applied to test errors of three-phase combined transformers on site, many testing devices are needed while laboratory space is limited. Therefore, narrowing down the space that testing devices occupied appears to be crucial. This article designed and developed the gas-insulated high-voltage standard current transformer with all three phases in one enclosure. Its characteristics is that double shielding and shielding combined with balancing winding are used separately to restrain the influence of leakage current and magnetic field on the error of standard current transformer. Moreover, the article carried out the effect of leakage current and magnetic field on the error of standard current transformer. The results show that the influence of leakage current on the error of standard current transformer is less than 1/10 of the error limit. The influence of adjacent phase current on standard current transformer is less than 1/10 of the error limit. The high voltage standard current transformer with three phases in one enclosure, designed and developed in this article, is capable of testing errors of 10 kV three-phase combined transformers for measurement on the field with three-phase testing method.

1. Introduction

At present, three-phase combined transformers are widely used in 3-35 kV distribution network energy metering devices, which have many characteristics such as large number, wide application and great influence. Its operation performance directly affects the safe operation and economic benefits of the power corporation. Its good operational quality and good error characteristics are of great significance to ensure the safe and stable operation of power grid and the accuracy and fairness of power transaction [1-3].

The current error of three-phase combined transformer used for measurement is usually 0.2S. Standard of Technical Management Regulations for Electric Energy Metering Devices (D/L 448-2016, in China) [4] stipulates that current transformers and voltage transformers in operation should be regularly inspected on the spot. Therefore, it is necessary to carry out on-site inspections regularly for three-phase combined transformers in operation. At present, both manufacturers and testing departments use single-phase testing method to test the three-phase combined transformers on the spot, that is, only single-phase current is applied when testing the errors of current transformers, and only single-phase voltage is applied when testing the errors of voltage transformers. There are the following drawbacks in using single-phase testing method to test the three-phase combined transformers: a) In practice, the current transformer operations at high voltage, while the single-phase testing method tests at low voltage; (b) Three-phase combined transformer operates under the condition that three-phase current and three-phase voltage coexist, and only single-phase current or voltage is applied during test;



c) There are both current transformer and voltage transformer in three-phase combined transformer which is a narrow space, and they operations at the same time, and they inevitably have electromagnetic influence on each other. However, the single-phase testing method can't reflect the influence of electromagnetic field on the error. Researches showed that the error characteristics of current transformer couldn't be tested accurately under low voltage, and the current transformer with qualified error under low voltage might not be qualified under rated operational high voltage. It is necessary to carry out error testing under its actual operating voltage in order to obtain accurate results [5-11]. In order to test the errors of three-phase combined transformers more accurately, relevant standards such as mechanical industry standard Three-phase combined transformers (JB/T10432-2016, in China) [12] proposed that the three-phase testing method should be used to test the errors of three-phase combined transformers, that is, the error of three-phase combined transformers should be carried out under the conditions of three-phase voltage and three-phase current. At present, the three-phase testing method of three-phase combined transformers is being formulated.

Three-phase standard current transformers are needed for field error test of three-phase combined transformers by three-phase testing method. At present, some research has been done on the testing devices of three-phase combined transformers [13-14]. However, all standard current transformers are monolithic and there is no relevant literature on standard current transformers. Because of the limited field test site, in order to reduce the area occupied by test devices and meet the needs of error test of three-phase combined transformer in limited space and improve the universality of test devices, it is particularly necessary to develop high-voltage standard current transformer with three phases in one enclosure. Because gas insulation has the advantages of light weight and small volume, a high-voltage standard current transformer with three phases in one enclosure based on gas insulation is designed and developed in this paper.

Two problems need to be solved to ensure the high accuracy of high-voltage standard current transformer with three phases in one enclosure. Firstly, the leakage current of standard current transformer under high voltage will affect the error of standard current transformer. In literature [15] it was pointed out that when current transformer operated at high voltage, leakage current was produced due to the voltage difference between primary and secondary windings. The leakage current would affect the error of current transformer, and the accuracy of standard current transformer was higher, the influence of leakage current would be greater. Therefore, the technical problem of leakage current affecting the accuracy of standard current transformer must be solved. Secondly, the electromagnetic field generated by external current would affect the error of standard current transformer. In Literature [16-17] the influence of external current and magnetic field on the error of current transformer was analyzed, and it was pointed out that if the shielding measures of current transformer were insufficient, the external current and magnetic field would significantly affect the characteristics of current transformer. Because the high-voltage standard current transformer with three phases in one enclosure has close phase distances and high accuracy, it is necessary to solve the influence of magnetic field on the error of standard current transformer.

In this paper, a design scheme was proposed to reduce the influence of leakage current and magnetic field on the error of high-voltage standard current transformer with three phases in one enclosure. A high-voltage standard current transformer with three phases in one enclosure was developed, and the test of the influence of leakage current and magnetic field on the error of high-voltage standard current transformer with three phases in one enclosure was carried out.

2. Design of High-voltage Standard Current Transformer with Three Phases in One Enclosure

2.1. Overall Layout Design

The overall layout of high-voltage standard current transformer with three phases in one enclosure is shown in Figure 1. Standard current transformers of phase A, B and C are in zigzag distribution and placed in the center of the shell, each phase contains a current-raising equipment and standard current transformer. In order to further reduce the space occupied by the test equipment in the field test, the current-raising equipment and standard current transformer are designed as cylinders, with two inner

walls, one through primary conductor (primary conductor passes through both the lifter and standard current transformer), and the other through secondary conductor with gas insulation.

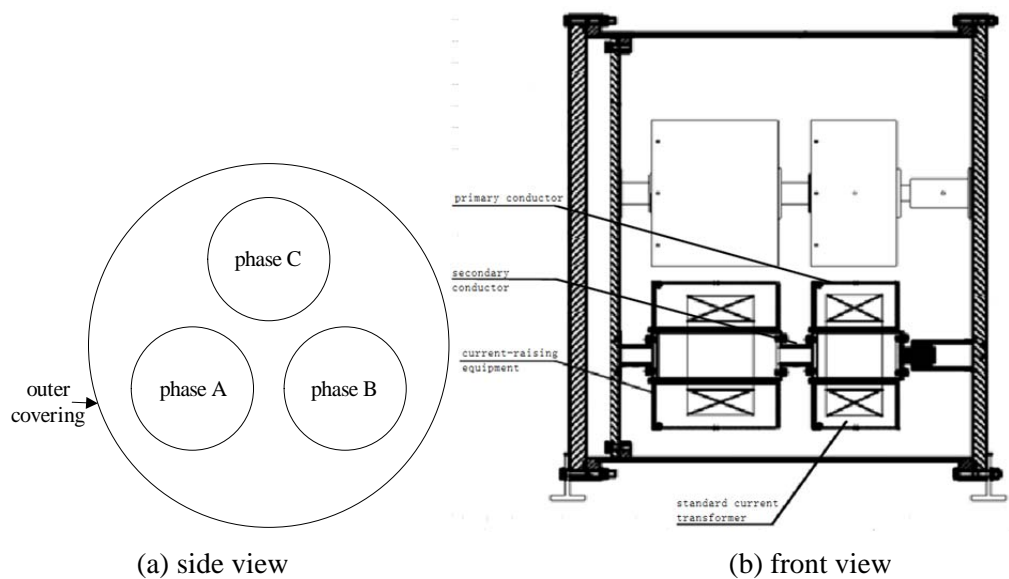
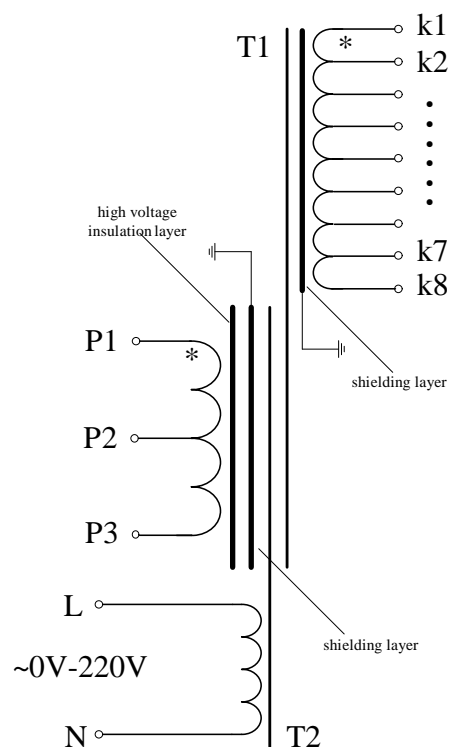


Figure 1. Overall layout of high-voltage standard current transformer with three phases in one enclosure



- T1——core of standard current transformer;
 T2——core of current-raising equipment;
 P1, P2, P3——primary winding tap of current transformer;
 k1, ..., k8——secondary winding tap of current transformer;
 L, N——Input end of current-raising equipment;

Figure 2. Design of anti-influence of leakage current

2.2. Design of Anti-leakage Current Influence

The design of each phase in high-voltage standard current transformer with three phases in one enclosure is the same. Therefore, only one phase is taken as an example. When standard current transformer carries out error test of current transformer at high voltage, its primary winding is at high voltage state, while the secondary winding is at low voltage (near zero potential) state, which results in leakage current between the primary winding at high voltage and the secondary winding at low voltage. The anti-leakage current effect design adopts double shielding design. As shown in Figure 2, the primary winding and secondary winding of current transformer are all wrapped with shielding layer and grounded. Using this design scheme, the capacitance between primary winding and secondary winding is reduced, and the leakage current flows into the earth through the shielding layer, which greatly reduces the influence of leakage current on the error of standard current transformer.

2.3. Design of Anti-magnetic Field Effect

In order to avoid the influence of magnetic field on the error of standard current transformer, shielding and balancing winding are used in combination in this design. In order to shield the adjacent standard current transformer from the magnetic field interference of the current of adjacent standard current transformer, an aluminum shielding barrel is added between standard current transformers. Balanced windings are installed in the secondary circuit of each standard current transformer, so that the magnetic force lines generated by the adjacent standard current transformer current produce two opposite electromotive forces in the standard current transformer, and the two electromotive forces cancel each other, further eliminating the interference of the phase magnetic field and the primary circuit electromagnetic field.

The design of the balancing winding is shown in Figure 3. (In the figure, a pair of balancing windings of the secondary winding of the B-phase standard current transformer balancing the current of the A-phase standard current transformer is analyzed as examples.) The balancing winding consists of two pairs of windings symmetrically arranged around the core. Each pair of windings is in series with anti-polarity, and each winding accounts for one fourth of the circumference of the core, and the number of turns is the same. The negative polarity connection of the balanced winding, in which the electromotive force induced by the main flux is zero, has no effect on the secondary winding, but balances the flux from point a to point b in the core, and achieves the purpose of balancing the external flux.

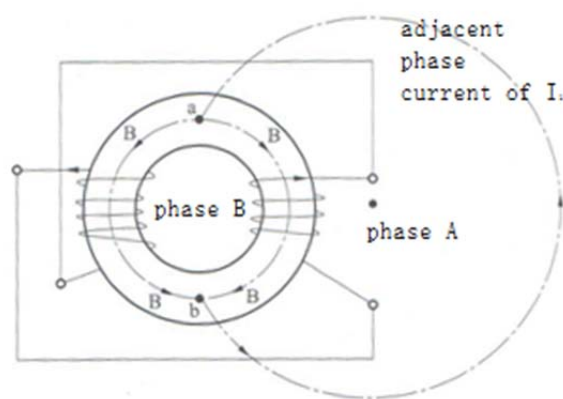
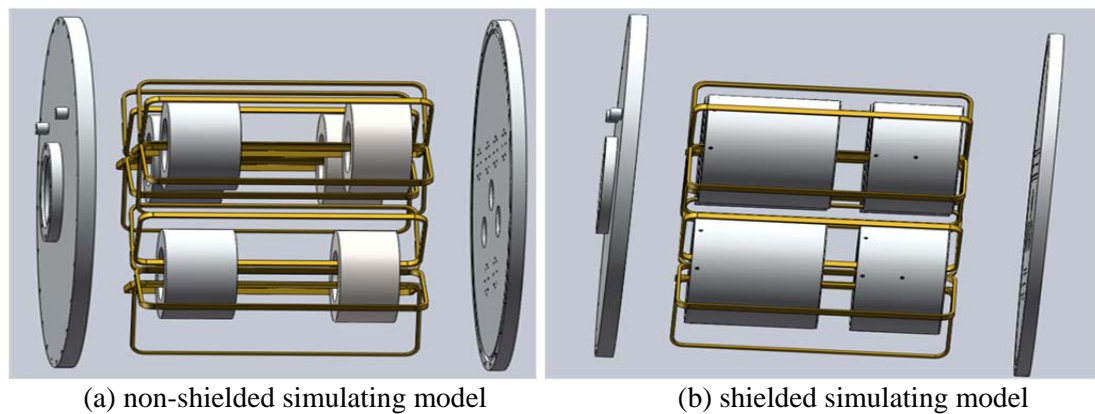
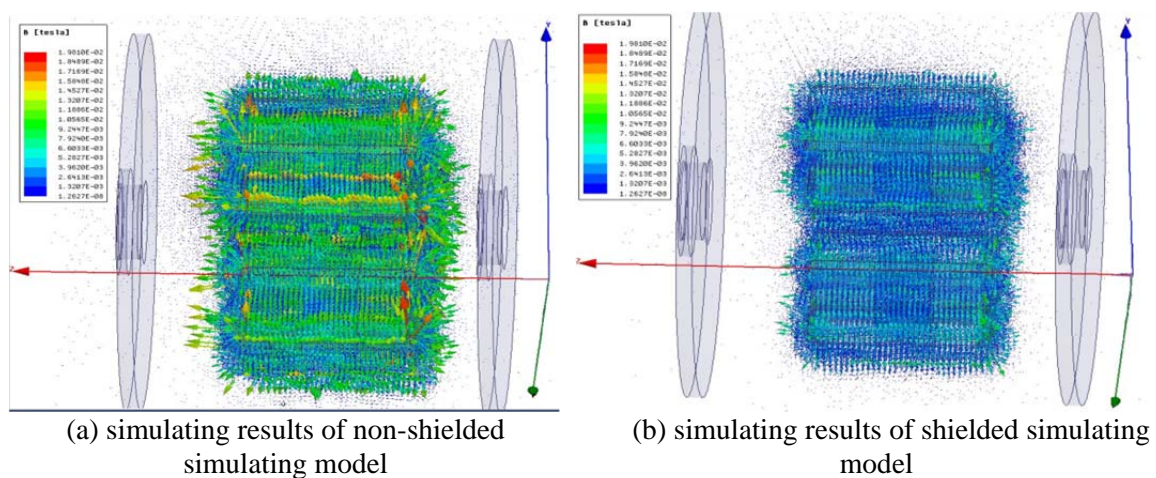


Figure 3. Design of balanced winding

**Figure 4.** Simulating model**Figure 5.** Results of simulation

2.4. Simulation Analysis of Shielding Effect

According to the above design, the simulation models without shielding and with shielding were constructed as shown in Figure 4. When the rated current was applied on phase A, the electromagnetic field distribution on the core of the standard current transformer was simulated. The results were shown in Fig. 5. It can be seen that the electromagnetic field on the core of standard current transformer of each phase is obviously reduced after shielding, so this design has a good effect.

3. Testing Performance of High-voltage Standard Current Transformer with Three Phases in One Enclosure

According to the above design scheme, a high-voltage standard transformer with three phases in one enclosure is developed. Its main technical specifications are shown in Table 1.

Table 1. Main technical specifications of high-voltage standard current transformer with three phase in one enclosure

Type	Technical index
Number of phase	3
Rated operational voltage	10kV
Rated primary current	10A~200A
Rated secondary current	5A
Accuracy	0.05S
Rated Secondary burden	5VA

Table 2. Errors of high-voltage standard current transformer with three phase in one enclosure

Ratio	Error	Percent of rated current (%)					Secondary burden
		1	5	20	100	120	
10A/5A	f (%)	-0.024	-0.023	-0.022	-0.019	-0.019	5VA
	δ (')	0.71	0.40	0.20	-0.05	-0.12	
	f (%)	0.046	0.002	-0.002	-0.001	-0.001	0VA
	δ (')	0.42	0.65	0.46	0.22	0.18	
200A/5A	f (%)	0.014	0.009	0.012	0.011	0.011	5VA
	δ (')	0.47	0.10	0.07	-0.01	-0.030	
	f (%)	-0.008	0.012	0.012	0.011	0.011	0VA
	δ (')	0.18	0.27	0.08	0.01	0.00	

3.1. Error of High-Voltage Standard Transformer with Three Phases in One Enclosure

According to standard of Verification Rules for Measuring Current Transformers (JJG313-2010, in China) [18], the error of the developed high-voltage standard current transformer with three phases in one enclosure was carried out. The maximum ratio of 200A/5A and the minimum ratio of 10A/5A are taken as examples for analysis. Taking the results of phase A as an example, its results are shown in Table 2. It can be seen that the results meet the requirements of the specification for the error limits of standard current transformers with 0.05S class.

3.2. Experiments of the Influence of Leakage Current on Error

The test of leakage current effect was carried out according to standard of GB 20840.4-2015 [19] and other standards [20]. The main function of resistance R is to convert leakage current signal into voltage signal for sampling, in order to improve the signal value, the standard resistance of 10 was selected as sampling resistance in leakage current test.

The maximum ratio of 200A/5A and the minimum ratio of 10A/5A are taken as examples for analysis. The errors of standard current transformers of each phase before and after applying voltage are shown in Table 3. The smaller the current is, the greater the influence of leakage current will be. This paper takes the case of standard current transformer under 1% rated current and rated secondary burden as an example to analyze. Before and after voltage application, the error variation of current transformer was less than 1/10 of the error limit (the ratio error and phase displacement limit of 0.05S class current transformer at 1% are 0.10% and 4', respectively), which met the requirements of the regulation. Therefore, the effect of leakage current on the error of standard current transformer can be effectively avoided by adding double shield in standard current transformer.

Table 3. Errors of high-voltage standard current transformer with three phase in one enclosure influenced by leakage current

Phase	Error	Without voltage		With 120% rated voltage	
		10A/5A	200A/5A	10A/5A	200A/5A
A	f (%)	-0.024	0.014	-0.020	0.010
	δ (')	0.71	0.47	0.65	0.44
B	f (%)	-0.018	0.009	-0.015	0.008
	δ (')	0.47	-0.17	0.43	-0.15
C	f (%)	-0.027	0.034	-0.022	0.030
	δ (')	0.84	0.30	0.80	0.27

Table 4. Errors of high-voltage standard current transformer with three phase in one enclosure influenced by magnetic field

Type	Error	Percent of rated current (%)				
		1	5	20	100	120
No current imposed on phase A and B	f (%)	0.038	0.009	0.007	0.007	0.007
	δ (')	0.82	0.37	0.19	0.04	0.03
200A imposed on phase A and B	f (%)	0.031	0.011	0.005	0.008	0.008
	δ (')	0.89	0.30	0.14	0.05	0.05

3.3. Experiments of the Influence of Magnetic Field on Error

In order to test the influence of the magnetic field produced by the overcurrent of the adjacent standard current transformer on the standard current transformer, this paper took phases of A and B standard current transformers into different primary currents and tested the error of the C phase standard current transformer (under the rated secondary burden, i.e. 5VA) as an example to test the influence of the magnetic field on the error of the standard current transformer. The experimental results were shown in Table 4. It can be seen that the error of phase C current transformer satisfies the error limit requirement of current transformer with 0.05S class when phases of A and B are not current-added and phases of A and B are applied 200 A currents, and the error difference is less than 1/10 of the error limit, which indicates that the influence of magnetic field on the error of standard transformer can be neglected.

4. Conclusion

In this paper, a high-voltage standard current transformer with three phases in one enclosure with rated voltage of 10 kV is designed and developed. The influence of leakage current on the error of standard current transformer is suppressed by double-layer shielding design, and the effect of phase magnetic field on the error of standard current transformer is suppressed by combining shielding with balancing winding. The test results showed that the leakage current had less than 1/10 of the error limit of the standard current transformer and the adjacent phase current had less than 1/10 of the error limit of the standard current transformer. The developed high-voltage standard current transformer with three phases in one enclosure can test the current error of three-phase combined transformer with rated voltage of 10 kV with 0.2S class.

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