Power Frequency Voltage Ratio Standard Self-calibration Based On Semi-insulating Voltage Series Summation

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Abstract: In order to study and improve the level of the 110kV frequency voltage ratio standard self-calibration system to meet the requirement of both the rapid development of power grid and voltage transformer test/calibration below 0.005 level, a traceability method based on semi-insulating voltage series summation is proposed. By analyzing the error of the mathematical models based on between the semi-insulating and fully insulating voltage series summation, the analysis indicates that the self-calibration system based on semi-insulating voltage series summation has both higher degree of accuracy and opening with great flexibility. The tests show that new self-calibration system achieves the desired specification.

Keywords: Self-calibration system, semi-insulating, voltage series summation, voltage transformer

1 Introductions

With the rapid development of Chinese electric power industry and the great increase of production level, the accuracy degree with delicate voltage transformer promotes rapidly as well, especially the proposal of establishing special high voltage example project and lay outing the intellective power grid, which challenges the test capability of frequency voltage ratio standard in china.

On the basis of voltage series summation, 110kV frequency voltage ratio standard self-calibration system developed by National high-voltage metering station in 1992, as the highest frequency voltage ratio standard, is employed in voltage transformer test/calibration below 0.01 level in the whole country. The accuracy degree of 110 kV voltage transformers is generally up to and even superior to 0.01 level[1], and as the innovation of technology, it will keep increasing. In order to follow the development of actual production level, and upgrade 110 kV frequency voltage ratio standard self-calibration system to guarantee that it can test the uncertainty exactly to 1×10^{-5} degree, this article proposes 110 kV frequency voltage ratio standard self-calibration system. One hand, the self-calibration raises Chinese technology system in frequency voltage ratio standard to the leading level internationally[2,3]; on the other hand, the upgraded self-calibration system can be adopted in voltage transformer test/calibration at 0.005 level and even below 0.005 level[4]. the new self-calibration system will contribute greatly to the traceability method and magnitude convey of frequency voltage ratio standard as well as the establishment of independent and sound calibration system in every institution nationwide.

2 The principle of semi-insulating voltage series summation

Self-calibration is to identify the accuracy degree of magnitude in a system without known standard magnitude outside this system. 110kV frequency voltage ratio standard self-calibration dates from voltage summation. The basic ratio comes from the summation of multi-terminal electric potential in 1kV single-disc inductive voltage divider , while ratio scale-up becomes practical through the series summation of two transformers with the same transformation ratio。Based on the currently principles "reference electric potential method" and "voltage series summation"[5] used by 110 kV frequency voltage ratio standard in china, in the new self-calibration system, semi-insulating voltage series summation will replace the current fully insulating shielded voltage series summation[6,7]. The difference between them lies in that all 3 transformers T1, T2, and T3 are semi-insulating. In T2, there will be a separate unit set up between the primary winding and the secondary winding to separate the high voltage circuit in the primary winding, while T1 in figure 2 is a fully insulating shielded transformer.

Voltage series summation is an approach to test transformer voltage coefficient. The Rated voltage ratio of T1,T2 and T3 in figure 1 are the same, marking K. ΔU means difference measuring voltage, and U_{ref} represents reference voltage.

When the primary and the secondary,T2 and T3 are connected in series. The primary winding of main standard voltage transformer T1 is connected parallelly with

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the primary winding of T2 and T3 which have been in series. In the secondary, the secondary voltage of T2 and T3 which have been in series is referred to measure the error of T1. Suppose the error of T1, T2 and T3 are α、β、γ. When the voltage is 2U in A-X, the error of measuring T1 isε_1。 In addition, referring to T1 and T2 respectively, when the voltage is U, the error of measuring T1 isε_2、ε_3

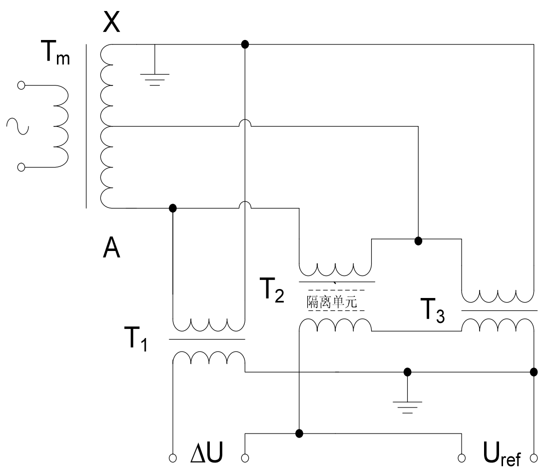

Fig 1 semi-insulating transformer voltage series summation circuit

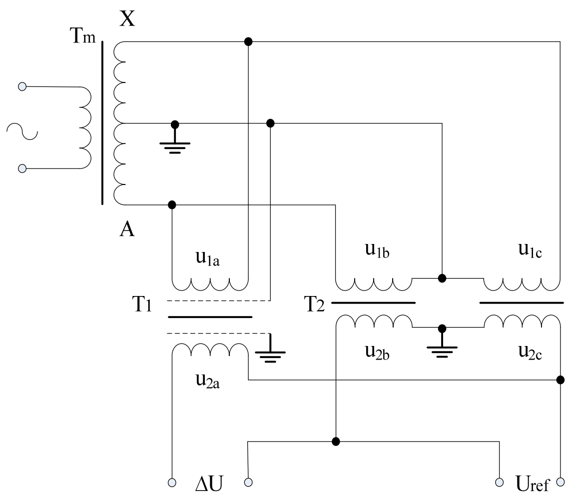

Fig 2 fully-insulating transformer voltage series summation circuit

$$\varepsilon_1 = \alpha(2U) - \frac{\beta(U)}{2} - \frac{\gamma(U)}{2} \tag{1}$$

In this formula, α(2U) is the error of T2 when the primary voltage is 2U. β(U)、γ(U) are separately the error of T_2、T_3 when the primary voltage is U. According to the circuit in figure 3, referring to T2 and T3 separately, the formulas to measure the errorε_2、ε_3 of T1 are as follows:

$$\varepsilon_2 = \alpha(U) - \beta(U) \tag{2}$$

$$\varepsilon_3 = \alpha(U) - \gamma(U) \tag{3}$$

According to the formulas （1）（2）（3）, a new one forms:

$$\alpha(2U) - \alpha(U) = \varepsilon_1 - \frac{(\varepsilon_2 + \varepsilon_3)}{2} \tag{4}$$

In this way, the three measurements can identify the error variation of T1 when the voltage is 2U and U, and then a relative curve revealing the relationship of error and voltage appears, namely voltage coefficient curve. Therefore, self-calibration from 1KV to 110KV frequency voltage ratio magnitude is finished through two voltage summations.

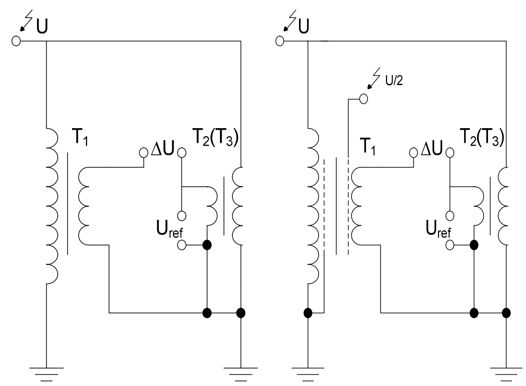

Fig 3 Mutual calibration circuit with voltage summation

3 Model error analysis

In the process of calibration, , when the shield potential changes because of the imperfect shield, leakage current goes across field copper, which makes an effect on the accuracy of transformers to some extent, and then on the measurement uncertainty of 110kV frequency voltage ratio standard equipment. In the process of calibration in figure 2 and 3, the shield potential and distributed capacitance makes changed the error of fully insolating voltage transformer and influence on uncertainty of the system[8].

There are two presumptions for fully-insolating transformer voltage series summation to calculate the voltage coefficient curve. One of them predicts that the potential of the excitation transformer T_m centretap which provides shield potential for transformers will not deviate; the other is that when measuring as the two circuits route in figure 2 and 3, the variation of transformers shielded potential will not influence the error characteristics. But in actual measurement, these presumptions could not be completely true.

In actual measurement, the centretap voltage of the excitation transformer which provides the central potential could not be symmetrical fully. Suppose side-play mount is ΔU , and $U_{1b} = U + \Delta U$, $U_{1c} = U - \Delta U$.

The formula (1) becomes:

$$\varepsilon_1 = \frac{U_{1a}(1+\alpha(2U)) - U_{1b}(1+\beta(U)) - U_{1c}(1+\gamma(U))}{U_{1a}(1+\alpha(2U))} \quad (5)$$

In brief, when $\alpha \ll 1$, $\beta \ll 1$, $\gamma << 1$, $\Delta U << U$,

$$\varepsilon_1 = \alpha(2U) - \frac{\beta(U)}{2} - \frac{\gamma(U)}{2} - \frac{\Delta U(\beta(U)-\gamma(U))}{2U(1+\alpha(2U))} \quad (6)$$

When high order component is ignored, and error variation of T2 and T3, $|\beta(U)-\gamma(U)| \le 1\times 10^{-4}$, is taken into consideration, central potential side-play mount of Tm is less than 1%, namely $\left|\frac{\Delta U}{2U}\right| \le 1\%$, $\left|\frac{\Delta U(\beta(U)-\gamma(U))}{2U(1+\alpha(2U))}\right| \le 1\times 10^{-6}$. So the error variation can be ignored in measurement.

Measured as the circuits route in figure 2 and 3, the shield potential of fully shielded transformers changes. Shield in figure 2 is earth potential. Shield and enclosure are equipotential. Shield in figure 3 lies in high potential. As a result, there is an electric potential difference between Shield and enclosure, which leads to leakage current, equaling to adding a stray capacitance to some point on field copper[9]. In mathematic model, it is just as a stray capacitance C is switched in some point in input circuit of equivalent T circuit[10], which is revealed in Figure 4. Z_{1a} and Z_{1b} in Figure 4 are representative of two impedance of field copper isolated by a stray capacitance C[11].

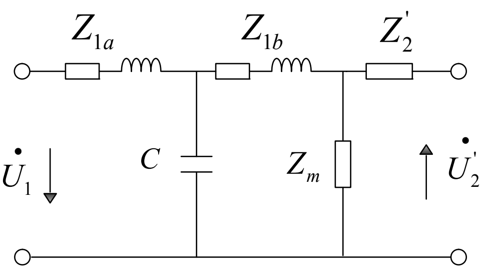

Figure 4: Equivalent T circuit of Shielded transformer

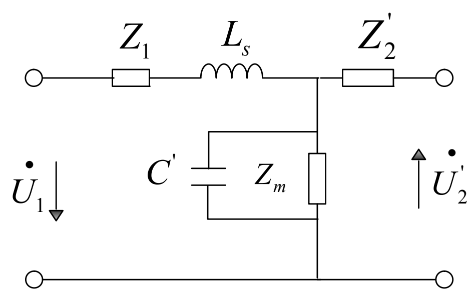

Fig 5 Equivalent circuit

After refining, the circuit diagram can be equivalent to what the figure 5 shows, in which C' is shunt capacitor, and L_s is the added inductance value on input circuit. Base on the definition of open-circuit error, there is a formula [12]:

$$\varepsilon_k' = -(Z_1 + X_{Ls})(Y_{C'} + Y_m) \quad (7)$$

In the formula: $\Delta\varepsilon = \varepsilon_k - \varepsilon_k' = (Z_1 + X_{Ls})Y_{C'} + X_{Ls}\cdot Y_m$, X_{Ls}、Y_m、$Y_{C'}$ represents separately condenser component of L_s and field transadmittance of Z_m, as well as the transadmittance of C'.

Z_1 is linear, and generally Y_m and C' mean nonlinear variation related to voltage. A stray capacitance will result in translation and distortion of the curve. The anticipation of mathematical model to calculate it is infeasible, because the influence of media nonlinearity on space electric field will make it difficult to simulate the form-complicated electric field. National high-voltage metering station has measured voltage coefficient of center potential shielded voltage transformer through experiments. The results indicated that the influence of translation and distortion degree on phase separation (10^{-5} level) is greater than that on ratio error（10^{-6} level), and the higher level of voltage, the greater influence.

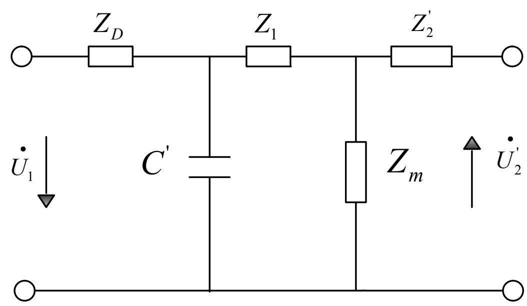

Figure 6 Equivalent T circuit of Semi-insulating transformer

In the process of Semi-insulating transformer voltage series summation measuring voltage coefficient, there is a potential difference in isolated voltage transformer. However, winding first tail and enclosure have equipotential, and the shield between the primary winding and secondary winding will connect the leakage current caused by Stray Capacitance to the ground directly, which equals that equivalent distributed capacitance is distributed in the both sides of the primary winding, as figure 6 shows.

In the formula $\overline{\varepsilon} = -Z_1 Y_m - jX_{C'}(\pm Z_D)$, Ym、$X_{C'}$ represent respectively excitation admittance and capacity of Zm、C', and $\pm Z_D$ is equivalent impedance. In figure 6, distributed capacitance is connected with primary winding in series directly. Therefore, Z_D=0, and the

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variation of open-circuit error $\Delta\varepsilon = 0$. Semi-insulating transformer voltage series summation circuit hasn't led to error as the potential difference occurs when measuring voltage coefficient.

3 Experiment

10kV reference point error is tested by the 1kV single-disc voltage divider and 200V multi-disc voltage divider, and both the voltage summation test and self-calibration were done according to the Equation 1 and Equation 3. We can obtain 10kV voltage error curve through the formula 4 treatment. Error of all points can be done by using difference method based on reference point combined with the voltage coefficient curve, and then the curve graphs were shown in Figure 7 and Figure 8[13], and all data were shown in tab 1.

110kV reference point error is tested by 10kV two-stage voltage transformer and 200V multi-disc voltage divider, and both the voltage summation test and self-calibration were done according to the Equation 1 and Equation 3. Through the formula treatment and method similar with 10kV error curve, the curve graphs were shown in Figure 9 and Figure 10, and all data were shown in tab 2.

Testing process showed that self-calibration system based on semi-insulating voltage series summation uses semi-insulating type transformer, which greatly increases system open to reduce the system measurement uncertainly, so that both the whole-insulating and semi-insulating voltage transformer can be measured[14]. Compared to single-stage voltage transformer, main standard devices including 6kV and 10kV, which are two-stage voltage transformer[15], improve the accuracy of their standard equipment.

Tab 1 10kV error data sheet

Up/Un% / Error10^{-6}		10	15	20	30	40	60	80	100	120	127
10kV reference Point Error	f	-6	-5								
	δ	-8.45	-8.25								
10kV voltage coefficient	f		0.05	-0.13	0.1	0.13	0.05	0.48	0.43	0.03	0.1
	δ		0.28	0.13	0.25	0.28	0.28	0.33	0.2	0.35	0.53
10kV voltage error curve	f	-8.1	-7.1	-8.3	-7.0	-8.1	-7.0	-7.7	-7.0	-7.0	-7.1
	δ	-7.7	-7.2	-7.6	-7.2	-7.3	-7.0	-7.0	-6.8	-6.7	-6.4

Tab 2 110kV error data sheet

Up/Un% / error10-6		10	15	20	30	40	60	80	100	120
110kV reference Point Error	f	-88.8	-66.3	-51.4						
	δ	48.6	54.65	56.05						
110kV voltage coefficient	f			31.2	31.05	31.9	33.5	32.7	31.45	29.9
	δ			4.0	-2.15	-4.95	-5.55	-6.25	-7.45	-9.1
110kV voltage error curve	f			-63.2	-45.9	-31.3	-12.7	1.39	11.13	17.15
	δ			47.25	44.03	42.3	38.48	36.05	32.32	29.38

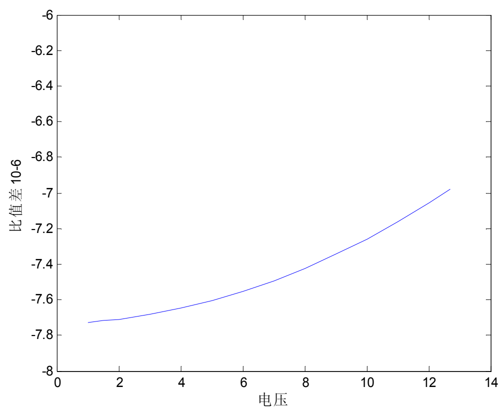

Fig 7 10kV ratio error curve

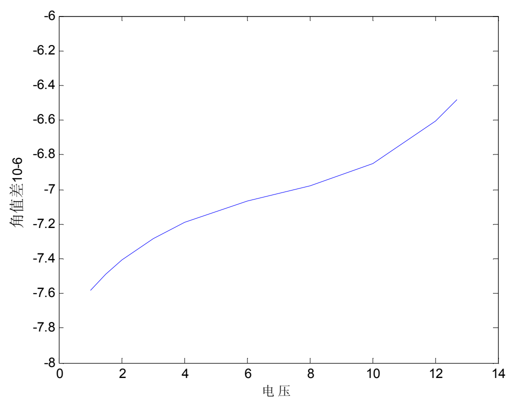

Fig 8 10kV phase error curve

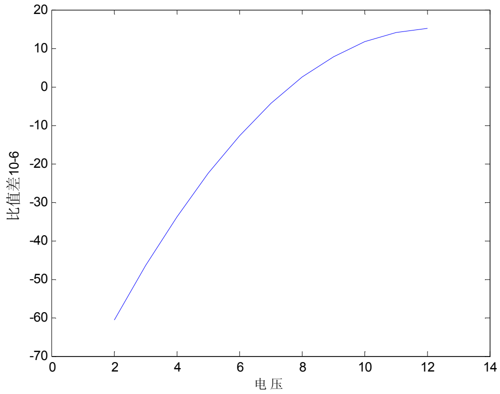

Fig.9 110kV ratio error curve

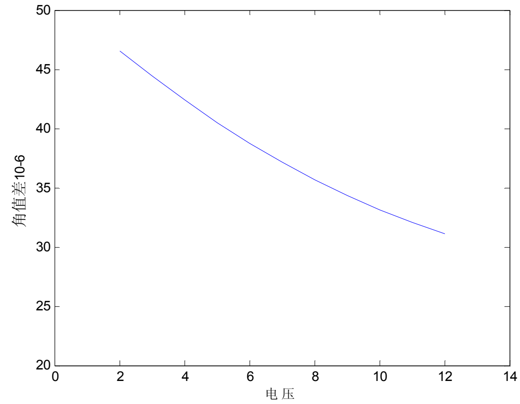

Fig.10 110kV phase error curve

4 Conclusion

a) The results through the comparison between semi-insulating and fully insulating voltage series summation reveal that the new self-calibration system based on semi-insulating voltage series summation reduces uncertainty caused by shielded potential, so its accuracy degree is higher.

b) The new self-calibration has better openness, which decreases the restriction that main standard in self-calibration must be a fully insulation shielded voltage transformer. What's more, all the standard equipments are made of SF6 gas insulation, which dramatically reduces the volume and weight of equipments and ensure the convenient and easy maintenance and measurement

c) the results indicate that the accuracy degree of the new self-calibration meet the anticipated determination-10kV and below is 2×10-5, 110kV and below is 5×10-5，which outperforms the original one in index. The new self-calibration, as the china's highest standard, raises the technology level of 110kV frequency voltage ratio standard system to the leading level internationally.

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