Analysis on Method of Connection Test of AC Withstand Voltage of Power Transformer

Yang Xiaolei, Liu Junyu, Shi Diancai, Wang Jiaying, Li Jingqi, Wang Shuai, Jin Dai, Xu Haihang, Tong Xin

Fushun Power Supply Company, Liaoning Electric Power Company Limited, State Grid, China

Keywords: AC withstand voltage; wiring type; transformer; series resonance

Abstract: This paper briefly expounds the determination of transformer voltage value, and introduces the principles of power frequency AC withstand voltage, variable frequency series resonance withstand voltage and multi-frequency induced withstand voltage. It also expounds the AC withstand voltage wiring method, and demonstrates a simple way to test withstand voltage on low voltage winding.

1. Introduction

Running under power frequency voltage for a long time, the transformer must bear the highest running voltage U_m and all sorts of overvoltage. In order to identify the transformer insulation strength, the AC withstand voltage test must be carried out before operation. The transformer voltage tests can be classified into: (*a*) full wave impact voltage, (*b*) chopped wave impact voltage, (*c*) operating wave impact voltage, (*d*) power frequency AC withstand voltage, (*e*) variable frequency series resonance voltage, (*f*) multi-frequency induced voltage.

Restricted by the limit of site test conditions, (*d*), (*e*), and (*f*) become the most common three methods. (d), (e), and (f), and the matters needing attention in the field test are mainly discussed in this paper.

2. The value of AC withstand voltage

The level of the transformer's insulation exerts huge influence on the reliability of the running. The insulation level is ultimately determined by AC withstand voltage value of the transformer, and the withstand voltage value is closely related to various overvoltage. So the transformer insulation level is mainly considered to meet the requirement of the various overvoltages[1,2].

The AC withstand voltage of 220 kV transformer mainly involves the external overvoltage, while the internal overvoltage is for 330kV's. For the 220kV transformer, the insulation level is evaluated by (*a*). But due to the limit of site condition, we use (*d*) to replace, and we use (*f*) to replace (*c*) in 330 kV systems.

Because the withstand voltage value of the transformer is based on various overvoltages, we must first study the classification and form of overvoltage[3-5]..External overvoltage and internal overvoltage are contained in overvoltage, direct lightning overvoltage and induction lightning overvoltage. And flow wave overvoltage is contained in external overvoltage, power frequency overvoltage and operating overvoltage. Resonance overvoltage are contained in internal overvoltage.

In view of all kinds of over-voltage, the common AC withstand voltage value is given eventually in Liaoning Province, as shown in Table 1.

The withstand voltage value of the standard is effective for the assessment of transformer insulation level. For anyone among (*d*), (*e*), and (*f*), once its test voltage meets the standard, it can be concluded that the transformer insulation level can satisfy the operating conditions.

  DOI: 10.25236/mmmce.2019.136

Table 1 AC withstand voltage test voltage standards (kV)

AC rated voltage	AC withstand voltage			
	Oil immersed transformer		Dry type transformer	
	The factory test	Commissioning test	The factory test	Commissioning test
<1	5	4	3.2	2.5
6	25	20	22	17
10	35	28	30	24
66	140	112		
220	(360) 395	(288) 316		

3. The classification of the AC withstand voltages

AC withstand voltage test is the most effective and direct identification of transformer insulation strength, especially in the inspection of main transformer insulation partial defects, such as damp, cracking or loose during transportation.

It should be stated, in this article, that AC withstand voltage is the generic terms of (*d*), (*e*), and (*f*). And (*e*) is a special form of (*d*).

3.1. Power frequency AC withstand voltage

DC A minute test voltage is also called applied power frequency high voltage, or insulation AC test, or rated voltage short-time power frequency withstands voltage. It is an equivalent voltage wave to operating overvoltage, or chopped wave impact test voltage. The voltage distribution, waveform and frequency in AC withstand voltage is in consistent with the actual situation. Therefore, it can reflect the real insulation defects. Power frequency AC withstand voltage test working principle diagram for large capacity transformer and small capacity transformer are shown in Figure 1 and Figure 2.

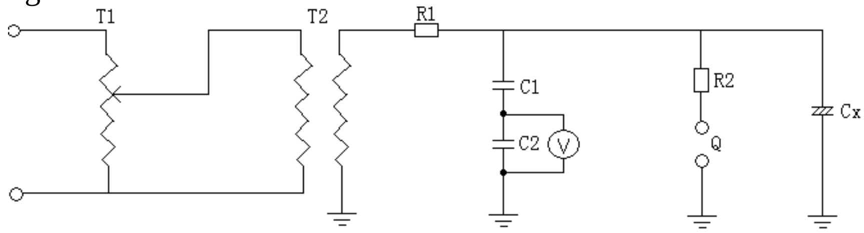

Fig.1 The principle diagram of AC withstand voltage test for large capacity transformer

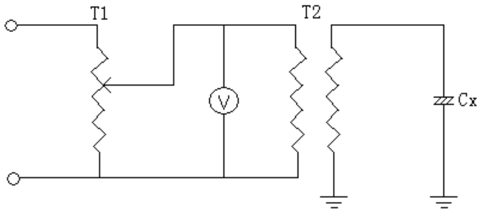

Fig.2 The principle diagram of AC withstand voltage test for small capacity transformer

3.2. Series resonance voltage

Because the capacitance ***C*** is very high, so the capacitive current I_C is higher, which requires the rated current of the high voltage testing transformer higher than 1A. The high voltage test of the transformer is rarely applied and the test power source can hardly meet the conditions at the site. Usually, we adopt series resonance voltage as an alternative, which is a special form of power frequency AC withstand voltage.

The method and wiring type of the series resonance voltage test is simple. We just put a certain value of reactor in the high voltage end. The frequency is obtained in circuit by adjusting the inductance and capacitance in the circuit to the series resonance state, which is $\omega L = \frac{1}{\omega C}$. The quality factor, $Q = \frac{\omega L}{R} = \frac{1}{\omega CR}$. The voltage on the transformer U_C then has the formula $U_C = U_L = QU_2$ (Q generally is more than 25). From this, we achieve the desired result----a low voltage in, and a high test voltage out. The series resonance voltage test device is portable and thus widely used on site. The working principle is shown in Figure 3.

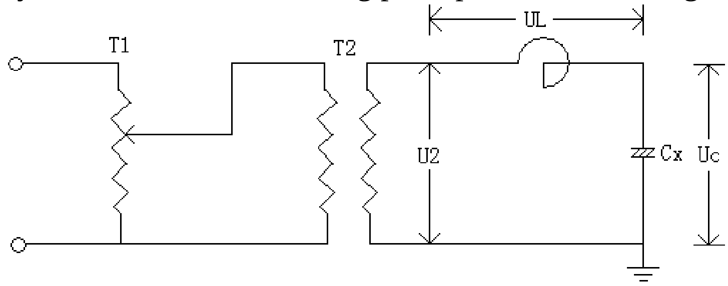

Fig.3 The working principle figure of the variable frequency series resonance AC voltage

3.3. Multi-frequency induced voltage

Power frequency AC withstand voltage test just checks the main transformer winding insulation strength, namely between the high, medium, low voltage windings and oil tank, iron core. Otherwise, the longitudinal insulation, namely, interlayer between stators, insulation between segments is not detected. Multi-frequency induced voltage can cover the lack. It is given a voltage, little higher than the rated, on the low voltage side and by electromagnetic induction in high voltage winding of the transformer, itself gets the trial voltage to check main insulation and longitudinal insulation, which is especially used in graded insulated transformer.

Basing on the formula, $E = KfB$, to improve the test voltage and not make the iron core saturation, we usually improve the power frequency. So, if we aim to double the voltage, we must double the frequency. Generally, we take 100~250 Hz power source. Figure 4 is the principle figure of multi-frequency induced voltage.

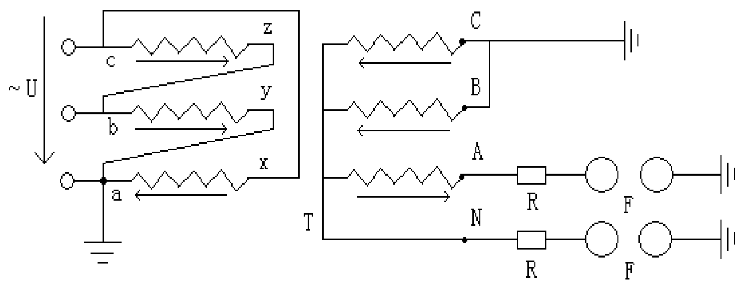

Fig.4 The working principle figure of the variable frequency series resonance AC voltage

4. The correct wiring method in ac withstand voltage test

For convenience, we take the single phase winding transformer as an example to illustrate. The high-voltage winding is represented by P, and low by S, grounding by E. The three phases of the high voltage side should be connected together and give the input trial voltage, while the low three phases should be connected together and then be reliably grounded.

The correct P-SE test wiring type is Figure 5.

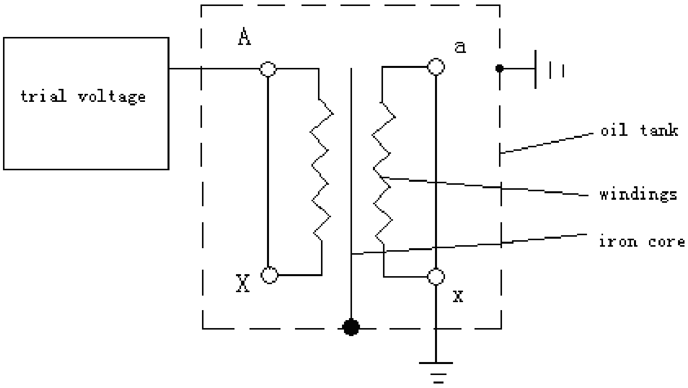

Fig.5 The correct P-SE test wiring type

Two wrong wiring types

4.1. The first P-SE test wiring type

The principle figure is shown in Figure 6 and from it, neither the high nor low three phases are connected.

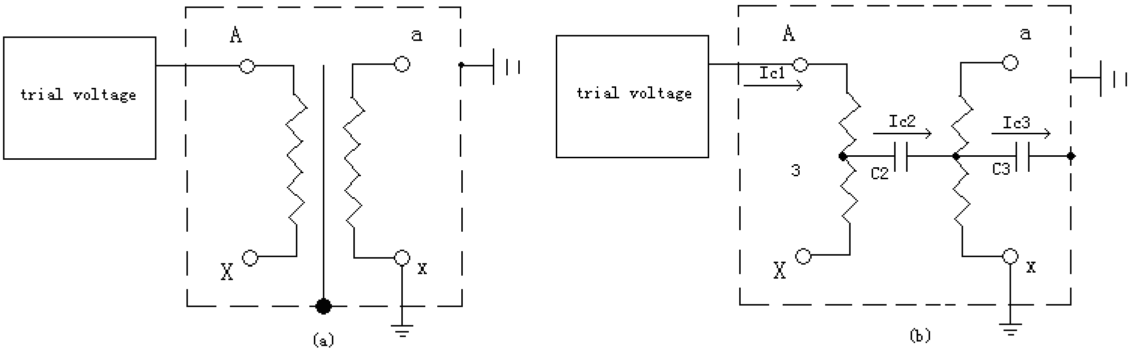

Fig.6 The first P-SE test wiring type

In this condition, as $C_2 \neq C_3$, $I_{C_2} \neq I_{C_3}$. Therefore, the voltage distribution in the windings is different. $U_X = U_A + \Delta U = U_A + I_C X_L$, and sometimes ΔU is big enough to occur flashover breakdown. Table 2 presents the trial data of a 66kV transformer.

Table 2 The trial data of a 66kV transformer.

Phase A (kV)	Phase B (kV)	Phase C (kV)	Neutral Point O (kV)
10	10.9	11.2	10.6
20	24.3	25.9	22.2
30	37.7	40.7	33.7
40	51.1	55.4	45.3
50	64.5	70.1	45.3
60	74.6	80.2	56.8
70	87.9	94.9	78.4
80	101.2	109.6	89.9
90	114.6	124.3	101.5
100	128	139	113

(Phase A is given the trial voltage, Phase B, C and neutral point O are ungrounded.)

4.2. The second P-SE test wiring type

In this situation, the windings are connected as required, but the low side is ungrounded. Figure 7 (a) is the voltage distribution diagram and Figure 7(b) is the capacitance distribution diagram.

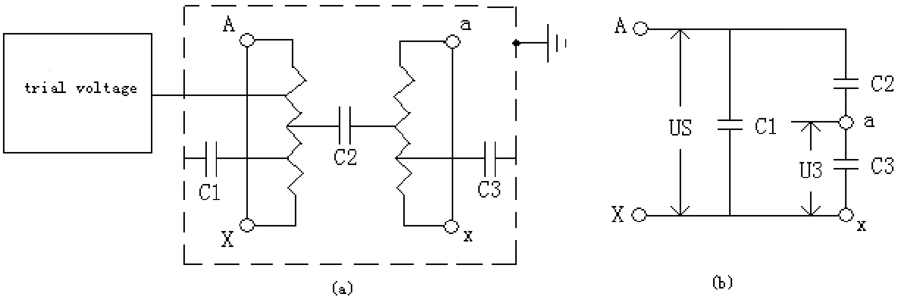

Fig.7 The second P-SE test wiring type

Now take a 66kV transformer for an example. We get the capacitance values through the site trial. $C_1 = 4500, C_2 = 4100, C_3 = 9300$. The trial voltage $U_{S_1} = 140(\text{kV}), U_{S_2} = 35(\text{kV})$.

So, $U_3 = \dfrac{C_2}{C_2 + C_3} U_{S_1} = \dfrac{4100}{4100 + 9300} \times 140 = 42.8(\text{kV})$

Since $42.8\text{kV} < U_{S_2} = 35(\text{kV})$, the low winding may occur grounding discharge. So it cannot be used in power frequency ac withstand voltage trial.

4.3. S-PE wiring types

In this occasion, the high voltage windings just need be connected. We need not to consider whether it is grounded or not. We again take the example above.

$C_1 = 4500, C_2 = 4100, C_3 = 9300$. The trial voltage $U_{S_1} = 140(\text{kV}), U_{S_2} = 35(\text{kV})$.

So, $U_1 = \dfrac{C_2}{C_1 + C_2} U_{S_2} = \dfrac{4100}{4500 + 4100} \times 140 = 66.7(\text{kV})$.

Because $66.7\text{kV} < U_{S_1} = 140(\text{kV})$, the induced voltage on the high side can never reach the value to discharge. Therefore, there are three S=PE wiring types, and the diagrams are shown in Figure 8.

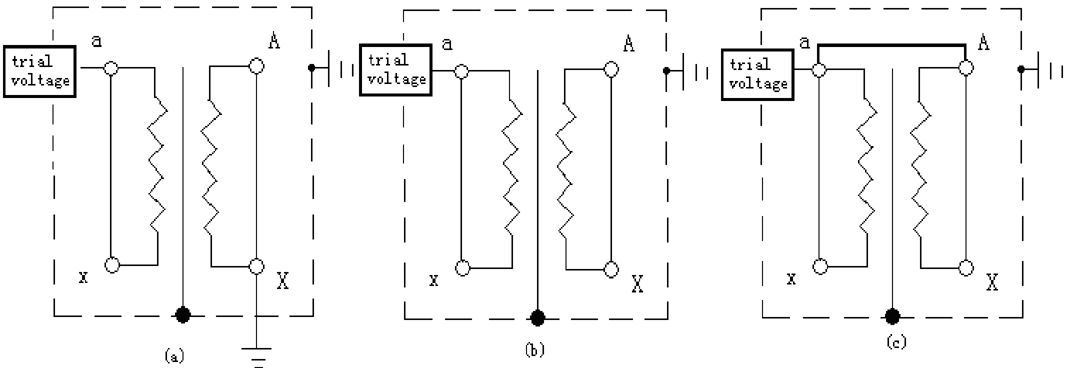

Fig.8 Three kinds of S-PE wiring types

Figure 8(a) inspects three insulation parts, between the low voltage winding and the iron core (or the oil tank), between the low voltage winding and the high voltage winding, between the low voltage winding and the oil tank.

Figure 8(b) inspects three insulation parts, between the low voltage winding and the iron core (or the oil tank), between the low voltage winding and the high voltage winding (the high side is ungrounded), between the low voltage winding and the oil tank.

Figure 8(c) inspects two insulation parts, between the low voltage winding and the iron core, between the low voltage winding and the oil tank.

5. Conclusion

(1) To do the press trial, the windings at each side should be connected together separately.

(2) Must use the correct P-SE test wiring type.

(3) The S-PE method is also available in site test. We can choose either of the three according to the working condition of the equipments.

(4)When using the variable frequency series resonance voltage method, we must notice that in the formula, $I_C = \omega CU$, the value of ω is not 314 rad/s again. It should be calculated with the following formula, $\omega = \frac{1}{2\pi\sqrt{LC}}$, $I_C = \frac{1}{2\pi\sqrt{LC}}CU$.

References

[1] Yin Kening. Design Principles of Transformer [M]. Beijing: China Power Press, 2010.

[2] WANG Shige. Fault analysis and technical improvements [M]. Beijing: China Power Press, 2004.

[3] DL/T596-1996 Preventive Test Code for Electric Power Equipment [S]. 1996

[4] Si Zengyan. Diagnosis and Treatment of Faults in 110 kV Transformers [J]. High Voltage Apparatus, 2007, 43(2): 157-158.

[5] Chen Huagang. Manual of abnormal operation of electrical equipment and incident handling [M]. Beijing: China Power Press, 2009.