Analysis of Causes for Faults Arising in the AC Withstand Voltage Test of 35kV Power Transformer

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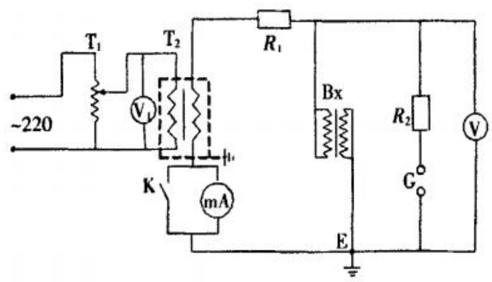
1. Introduction

The AC withstand voltage test of power transformer aims to detect the main insulation strength of winding to ground or between windings, which is an important method of avoiding insulation faults. It plays a decisive role in whether power transformer can be put into operation. Therefore, Preventive Test Code for Electric Power Equipment stipulates that AC withstand voltage test must be conducted for 66kV and above power transformer if overhauled. The test falls into the category of destructive test because test voltage is far higher than operation voltage. Follow the instructions very strictly when conducting the test. Otherwise, it could lead to broken equipment.

2. Faults

The AC withstand voltage test was carried out for a set of overhauled 35kV power transformer on July 28, 2006. The test wiring is shown in Fig.1 The model of power transformer is SF9-10000/35 and rated voltage is (35±2.5%)/10.5kV. After the maintenance, all data of destructive test (dielectric resistance) are qualified and stewing for over 24h. The AC withstand voltage value for high voltage side of power transformer to low side and the ground is 85kV. According to Preventive Test Code for Electric Power Equipment, test voltage shall be 85% of delivery test voltage and actual applied voltage is 72kV. The capacitance of HV side to LV side and ground is 5569pF. If AC withstand voltage value is 72kV, output current of transformer HV winding is 0.126A and LV side current is 47.25A. The power transformer fully meets the requirement of field test.



T_1 - voltage regulator

T_2 - test power transformer

R_1 - current-limiting water resistance

R_2 - sphere gap protective water resistance

G - sphere gap

V - digital display voltmeter

K - short circuit

mA - milliammeter

Bx - power transformer tested

Fig.1 Diagram of AC withstand voltage test wiring

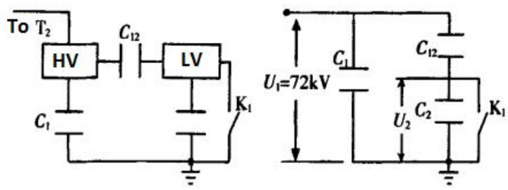
According to Fig.1, LV winding terminal short connection of power transformer is grounded; HV winding terminal short connection is connected with HV output winding of power transformer. All grounding lines are After all lines are checked with no deviation, the spacing between protective sphere gaps is adjusted. The discharge voltage is set 82kV; then the AC withstand voltage is conducted for HV side of power transformer. When the test voltage rises to 72kV, the surface of 10kV side bushing discharges and loud discharge sound is heard. The control switch trip of test transformer appears and voltage regulator returns to zero automatically. The close inspection reveals that all equipment grounding lines fall off at the grounding point E. In addition, the milliammeter, short circuit knife switch and digital voltmeter are broken and insulation resistance is zero. All shows that the insulation of test transformer are subject to the damage.

3. Cause Analysis

According to the inspection on site, the main cause for this fault is that all equipment grounding lines twine and then are bound to flat iron at the grounding point E. It is likely that copper lines break up so that the grounding is not secure. When the test voltage rises to 72kV, all grounding lines fall off at flat iron; then transient over-voltage generates, which causes 10kV bushing to discharge and damages test transformer.

3.1 Analysis of causes for 10kV bushing discharge

The wiring of AC withstand voltage test of HV side to LV side and ground is shown in Fig.2. In the Fig.2, C_1 is the capacitance of HV winding of power transformer to ground ; C_2 is the capacitance of LV winding to ground; C_{12} is the the capacitance between HV winding and LV winding. The dielectric tester is used to obtain the capacitance of HV winding to LV winding and ground C_g is 5569pF; the capacitance of LV winding to high winding and ground C_d is 9139pF; HV and LV winding to ground C_{g+d} is 6329pF.



(a) Wiring (b) equivalent circuit

Fig.2 Capacitance distribution when LV winding floats and grounding lines fall off

According to principles of dielectrics and capacitance wiring, three formulas are listed in the following:

$$C_g = C_1 + C_{12} \quad (1)$$

$$C_d = C_2 + C_{12} \quad (2)$$

$$C_{g+d} = C_1 + C_2 \quad (3)$$

$$C_{12} = \frac{C_d + C_g - C_{g+d}}{2} = 4189.5\text{pF}$$

$C_1 = C_g - C_{12} = 1379.5pF$

$C_2 = C_d - C_{12} = 4949.5pF$

Under normal conditions, LV winding short-circuit of tested power transformer is grounded, which amounts to the fact that knife switch K_1 in Fig.2 is closed and all points of LV winding are equipotential as the ground; when the LV side grounding lines of power transformer fall off, K_1 disconnects. Let's us assume that t=0 and K_1 disconnects, before disconnecting (t=0-), the voltage U_2 (0-) on C_2 is equipotential as the ground, thus U_2 (0-) =0; the instant after disconnecting ($t=0_+$), since the voltage of C_2 cannot change suddenly, initial voltage $U_2(0_+)=U_2$ (0-) =0; after some time, the voltage of LV winding to ground will reach a stable voltage value U_{2p}; at this point, the LV winding of power transformer is in floating condition and is in the electric field; the stable voltage value U_{2p} depends on C_{12} and C_2.

$$U_{2p} = \frac{C_{12}}{C_{12} + C_2} U$$

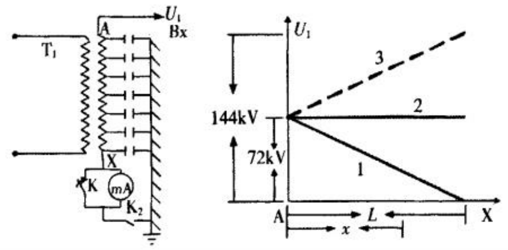
$U_{2p} = 33kV$

Because the initial voltage is different from stable voltage, there is a transient process when the voltage of HV winding rises from 0 to 33kV. During this process, far more than 33kV voltage will generate on the all points of LV winding. According to three elements of circuit principle, transient voltage $U_2 = U_{2p} + [U_{2p} - U_2 (0_+)] e^{-8t}$. Hence, U_2 attenuates as the time increases. It is concluded that t = 0, U_2 is the biggest and $U_{2max} = U_{2p} + [U_{2p} - U_2 (0_+)] \rightarrow U_{2max} = 2 \times 33 = 66KV$.

The delivery and maintenance test voltage value of power transformer 10kV winding is 35kV and 30kV respectively. Hence, maximum U_2 could lead to the damage of winding insulation of LV winding. If non-destructive test and AC withstand voltage test are qualified, it shows that power transformer is intact and can be put into operation again.

3.2 Analysis of Damage to Test Equipment

The simplified equivalent circuit of HV output winding is shown in Fig.3a-line 1. Under the influence of power frequency voltage, the capacitance between turns is small and capacitive reactance is not big. Besides, the capacitance and mutual inductance is neglected. The knife switch K, which is in parallel with the milliammeter, is always closed during the process of voltage rising. Only when you read the milliammeter can the knife switch disconnect. The HV output winding end of test transformer X is grounded. In other words, the knife switch K_2 is closed. At the power frequency voltage, the voltage of all points on the winding is evenly distributed. The value $U = U_1(1- \frac{x}{L})$ (L represents the length of winding, x represents the distance of every point to A). Let's us assume that t=0 and K_2 disconnects, before disconnecting (t=0-), $U(0-)=U=U_1(1- \frac{x}{L})$ and winding front end x=0, so $U(0-)=U_1$; at tail end X, x=1 U(0-)= 0, which is shown in Fig.3b -1. When K_2 disconnects $t=0_+$, since the voltage on the capacitance of HV winding to ground cannot change suddenly, every point initial voltage $U(0_+)$ is the same as t=0, namely, $U(0_+)=U(0_-)=U_1(1-\frac{x}{L})$; However, K_2 disconnects and reaches a steady state, steady-state voltage of all points of power transformer HV output winding is the same, that is, $U_p=U_1=72kV$, which is shown in Fig.3b-line 2.



(a) Simplified equivalent circuit (b) potential distribution

Fig.3 Equivalent diagram of HV winding of power transformer

Based on the above analysis, the distribution of initial voltage of all points of HV output winding is different from that of steady-state voltage. Hence, there is a transient process from initial distribution to steady-state distribution. Each point on the winding generates transient over-voltage, which is different from that of 10kV winding of test transformer. The transient over-voltages of all points of 10kV winding are the same and the time of maximum voltage value is consistent. However, the situation is different here. The envelope of maximum voltage is shown in Fig.3b-dotted line 3. $U_{max}=U_p+[U_p-U(0_+)]\rightarrow U_{max}=U_1(1+\frac{x}{L})$ x=1, $U_{max}=2U_1=144kV$. To summary, one maximum voltage value would generate at all points of HV winding during the transient process, but the one generated at the end represented by the letter X is higher than that of any other points.

The above-mentioned transient voltage causes serious damage to test equipment. Three reasons are as follows. First of all, the closer HV output winding of test transformer is from tail end, the weaker its insulation is. The high voltage arising during the transient process is more likely to cause insulation breakdown of high voltage winding to low voltage winding and the ground; secondly, under the influence of transient over-voltage of winding tail end, the milliammeter and short circuit knife switch are likely to breakdown and burn; thirdly, grounding lines of digital voltmeter fall off, front voltage of test transformer would burn it; at last, if grounding lines fall off, testers are taking readings at that time, which will pose a serious threat to them.

4. Precautions

Two precautions are put forward in this paper against the fault occurring in this AC withstand voltage test. First of all, to improve the grounding method; secondly, to improve the method of milliammeter wiring and reading.

4.1 Improvement of grounding method

The following precautions should be taken in the aspect of test grounding:

① Fixed connection methods such as screws should be adopted to reliably connect all grounding lines and earth mat; ② Grounding lines and points of different equipment are different so they are not grounded twining. In particular, grounding lines of test object should be grounded separately from those of other test equipment; ③ The sectional area of equipment connection line or grounding line should be large enough to meet the requirements of dynamic and thermal stability; ④ Some staff should be assigned to check whether the wiring is fixed and the safety space is enough. Tests can be carried out only if all wiring is correct.

4.2 Improvement of milliammeter wiring

In this test, a milliammeter is installed and one knife switch represented by the letter "K" is connected in parallel, which prevents short circuit current from burning the milliammeter. It is necessary to improve the milliammeter wiring. The knife switch can be changed to LA normally-closed button, which is shown in Fig.4. This button remains closed during the step-up process. It opens only when you press it to take readings. When taking readings, testers are advised to stand outside safety distance and press the AN button by means of one insulation rode. If the scale is not clear, the telescope is recommended to take readings.

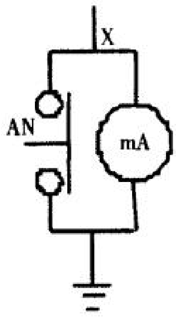


Fig.4 Diagram of milliammeter wiring

5. Conclusions

(1) The AC withstand voltage test is mainly used for examining the condition of main insulation. When conducting the test, the test winding short circuit should step up while non-test winding short circuit should be grounded in order not to cause damage to insulation. In this test, although the voltage of LV winding rises to 66kV, no fault and damage arise.

(2) The voltage applied in the AC withstand voltage test is very high, so equipment shell grounding lines and non-test winding lines must be well connected. In addition, all test wiring lines should not be grounded at the same place. In this test, because non-test winding grounding lines of power transformer are not well grounded, transient over-voltage reaches two times of test voltage, doing damage to test equipment.

(3) The LA normally-closed button is recommended to replace the parallel knife switch. Testers are advised to stand outside safety distance and press the AN button by means of one insulation rode.

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