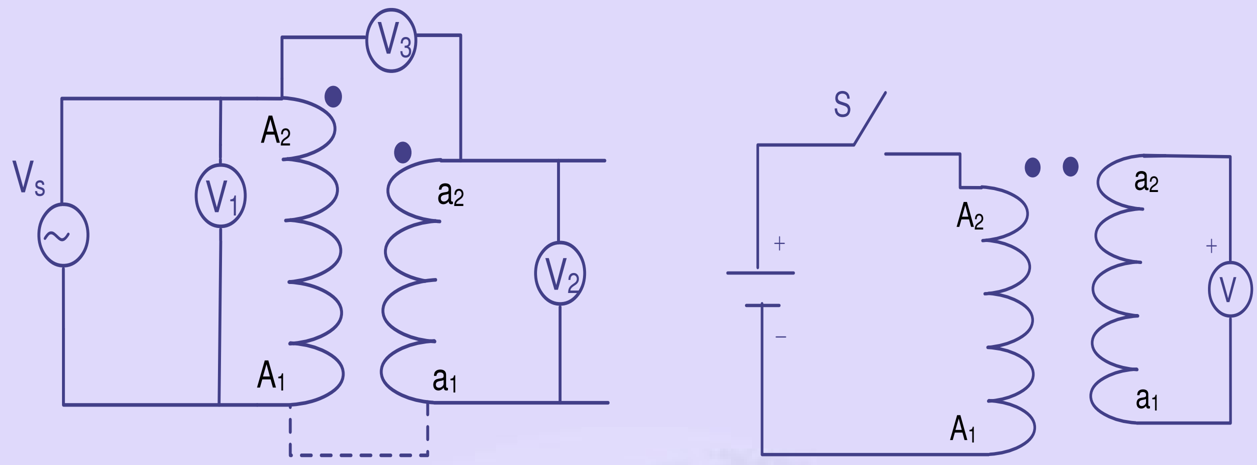
7 Testing of Transformers

The structure of the circuit equivalent of a practical transformer is developed earlier. The performance parameters of interest can be obtained by solving that circuit for any load conditions. The equivalent circuit parameters are available to the designer of the transformers from the various expressions that he uses for designing the transformers. But for a user these are not available most of the times. Also when a transformer is rewound with different primary and secondary windings the equivalent circuit also changes. In order to get the equivalent circuit parameters test methods are heavily depended upon. From the analysis of the equivalent circuit one can determine the electrical parameters. But if the temperature rise of the transformer is required, then test method is the most dependable one. There are several tests that can be done on the transformer; however a few common ones are discussed here.

7.1 Winding resistance test

This is nothing but the resistance measurement of the windings by applying a small d.c voltage to the winding and measuring the current through the same. The ratio gives the winding resistance, more commonly feasible with high voltage windings. For low voltage windings a resistance-bridge method can be used. From the d.c resistance one can get the a.c. resistance by applying skin effect corrections.



(a)A.C.test (b)D.C.test

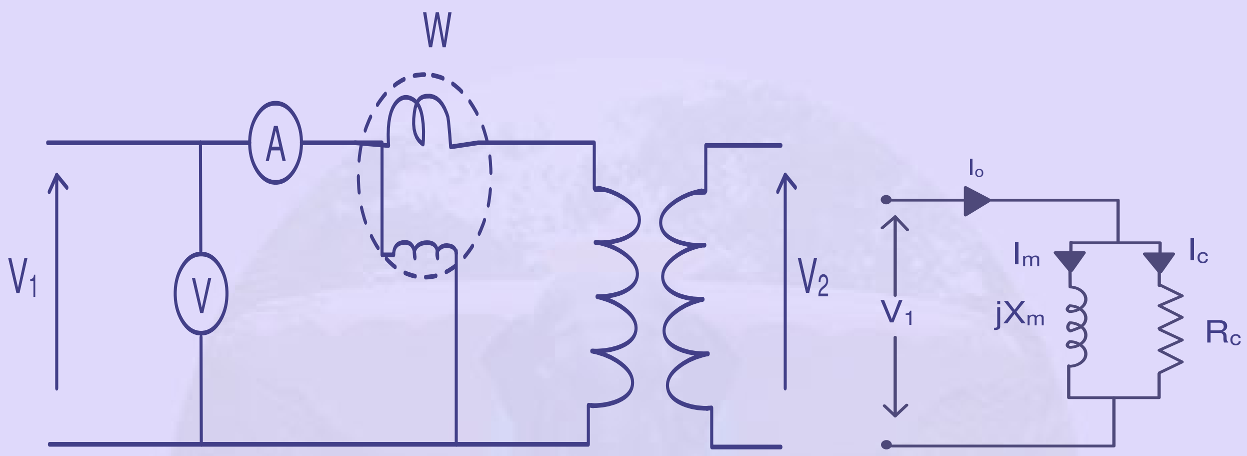
Figure 18: Polarity Test

7.2 Polarity Test

This is needed for identifying the primary and secondary phasor polarities. It is a must for poly phase connections. Both a.c. and d.c methods can be used for detecting the polarities of the induced emfs. The dot method discussed earlier is used to indicate the polarities. The transformer is connected to a low voltage a.c. source with the connections made as shown in the fig. 18(a). A supply voltage V_s is applied to the primary and the readings of the voltmeters V_1, V_2 and V_3 are noted. $V_1 : V_2$ gives the turns ratio. If V_3 reads $V_1 - V_2$ then assumed dot locations are correct (for the connection shown). The beginning and end of the primary and secondary may then be marked by $A_1 - A_2$ and $a_1 - a_2$ respectively. If the voltage rises from A_1 to A_2 in the primary, at any instant it does so from a_1 to a_2 in the secondary. If more secondary terminals are present due to taps taken from the windings they can be labeled as a_3, a_4, a_5, a_6. It is the voltage rising from smaller number towards larger ones in each winding. The same thing holds good if more secondaries are present.

Fig. 18(b) shows the d.c. method of testing the polarity. When the switch S is closed if the secondary voltage shows a positive reading, with a moving coil meter, the assumed polarity is correct. If the meter kicks back the assumed polarity is wrong.

7.3 Open Circuit Test



(a)Physical Arrangement

(b)Equivalent Circuit

Figure 19: No Load Test

As the name suggests, the secondary is kept open circuited and nominal value of the input voltage is applied to the primary winding and the input current and power are measured. In Fig. 19(a) V, A, W are the voltmeter, ammeter and wattmeter respectively. Let these meters read V_1, I_0 and W_0 respectively.Fig. 19(b) shows the equivalent circuit of the transformer under this test. The no load current at rated voltage is less than 1 percent of nominal current and hence the loss and drop that take place in primary impedance $r_1 + jx_{l1}$ due to the no load current I_0 is negligible. The active component I_c of the no load current I_0

represents the core losses and reactive current I_m is the current needed for the magnetization. Thus the watt meter reading

$$W_0 = V_1 I_c = P_{core} \tag{38}$$

$$\therefore I_c = \frac{W_0}{V_1} \tag{39}$$

$$\therefore I_m = \sqrt{I_0^2 - I_c^2} \quad \text{or} \tag{40}$$

$$R_c = \frac{V_1}{I_c} \quad \text{and} X_m = \frac{V_1}{I_m} \tag{41}$$

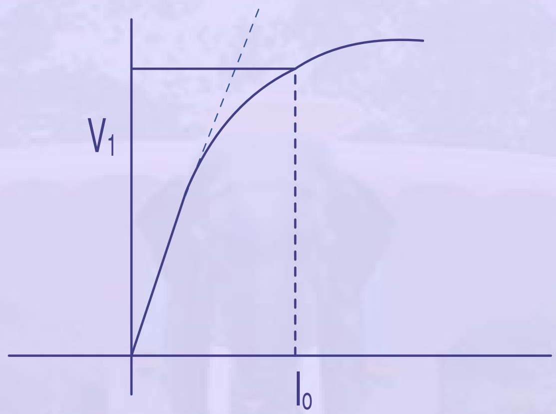


Figure 20: Open Circuit Characteristics

The parameters measured already are in terms of the primary. Sometimes the primary voltage required may be in kilo-Volts and it may not be feasible to apply nominal voltage to primary from the point of safety to personnel and equipment. If the secondary voltage is low, one can perform the test with LV side energized keeping the HV side open circuited. In this case the parameters that are obtained are in terms of LV. These have to be referred to HV side if we need the equivalent circuit referred to HV side.

Sometimes the nominal value of high voltage itself may not be known, or in doubt, especially in a rewound transformer. In such cases an open circuit characteristics is first obtained, which is a graph showing the applied voltage as a function of the no load current. This is a non linear curve as shown in Fig. 20. This graph is obtained by noting the current drawn by transformer at different applied voltage, keeping the secondary open circuited. The usual operating point selected for operation lies at some standard voltage around the knee point of the characteristic. After this value is chosen as the nominal value the parameters are calculated as mentioned above.

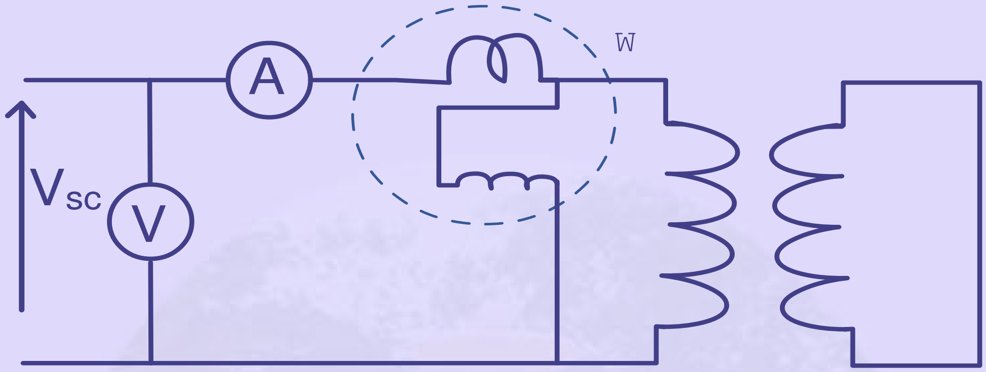
7.4 Short Circuit Test

The purpose of this test is to determine the series branch parameters of the equivalent circuit of Fig. 21(b). As the name suggests, in this test primary applied voltage, the current and power input are measured keeping the secondary terminals short circuited. Let these values be V_{sc}, I_{sc} and W_{sc} respectively. The supply voltage required to circulate rated current through the transformer is usually very small and is of the order of a few percent of the nominal voltage. The excitation current which is only 1 percent or less even at rated voltage becomes negligibly small during this test and hence is neglected. The shunt branch is thus assumed to be absent. Also $I_1 = I_2^{'}$ as $I_0 \simeq 0$. Therefore W_{sc} is the sum of the copper losses in primary and secondary put together. The reactive power consumed is that absorbed by the leakage reactance of the two windings.

$$W_{sc} = I_{sc}^2(r_1 + r_2^{'}) \tag{42}$$

$$Z_{sc} = \frac{V_{sc}}{I_{sc}} \tag{43}$$

$$(x_{l1} + x_{l2}^{'}) = \sqrt{Z_{sc}^2 - (r_1 + r_2^{'})^2} \tag{44}$$



(a)Physical Arrangement

(b)Equivalent Circuit

Figure 21: Short Circuit Test

If the approximate equivalent circuit is required then there is no need to separate r_1 and $r_2^{'}$ or x_{l1} and $x_{l2}^{'}$. However if the exact equivalent circuit is needed then either r_1 or $r_2^{'}$ is determined from the resistance measurement and the other separated from the total. As for the separation of x_{l1} and $x_{l2}^{'}$ is concerned, they are assumed to be equal. This is a fairly valid assumption for many types of transformer windings as the leakage flux paths are through air and are similar.

7.5 Load Test

Load Test helps to determine the total loss that takes place, when the transformer is loaded. Unlike the tests described previously, in the present case nominal voltage is applied across the primary and rated current is drown from the secondary. Load test is used mainly

1. to determine the rated load of the machine and the temperature rise
2. to determine the voltage regulation and efficiency of the transformer.

Rated load is determined by loading the transformer on a continuous basis and observing the steady state temperature rise. The losses that are generated inside the transformer on load appear as heat. This heats the transformer and the temperature of the transformer increases. The insulation of the transformer is the one to get affected by this rise in the temperature. Both paper and oil which are used for insulation in the transformer start getting degenerated and get decomposed. If the flash point of the oil is reached the transformer goes up in flames. Hence to have a reasonable life expectancy the loading of the transformer must be limited to that value which gives the maximum temperature rise tolerated by the insulation. This aspect of temperature rise cannot be guessed from the electrical equivalent circuit. Further, the losses like dielectric losses and stray load losses are not modeled in the equivalent circuit and the actual loss under load condition will be in error to that extent. Many external means of removal of heat from the transformer in the form of different cooling methods give rise to different values for temperature rise of insulation. Hence these permit different levels of loading for the same transformer. Hence the only sure way of ascertaining the rating is by conducting a load test.

It is rather easy to load a transformer of small ratings. As the rating increases it becomes difficult to find a load that can absorb the requisite power and a source to feed the necessary current. As the transformers come in varied transformation ratios, in many cases it becomes extremely difficult to get suitable load impedance.

Further, the temperature rise of the transformer is due to the losses that take place 'inside' the transformer. The efficiency of the transformer is above 99% even in modest sizes which means 1 percent of power handled by the transformer actually goes to heat up the machine. The remaining 99% of the power has to be dissipated in a load impedance external to the machine. This is very wasteful in terms of energy also. (If the load is of unity power factor) Thus the actual loading of the transformer is seldom resorted to. Equivalent loss methods of loading and 'Phantom' loading are commonly used in the case of transformers. The load is applied and held constant till the temperature rise of transformer reaches a steady value. If the final steady temperature rise is lower than the maximum permissible value, then load can be increased else it is decreased. That load current which gives the maximum permissible temperature rise is declared as the nominal or rated load current and the volt amperes are computed using the same.

In the equivalent loss method a short circuit test is done on the transformer. The short circuit current is so chosen that the resulting loss taking place inside the transformer is equivalent to the sum of the iron losses, full load copper losses and assumed stray load losses. By this method even though one can pump in equivalent loss inside the transformer, the actual distribution of this loss vastly differs from that taking place in reality. Therefore this test comes close to a load test but does not replace one.

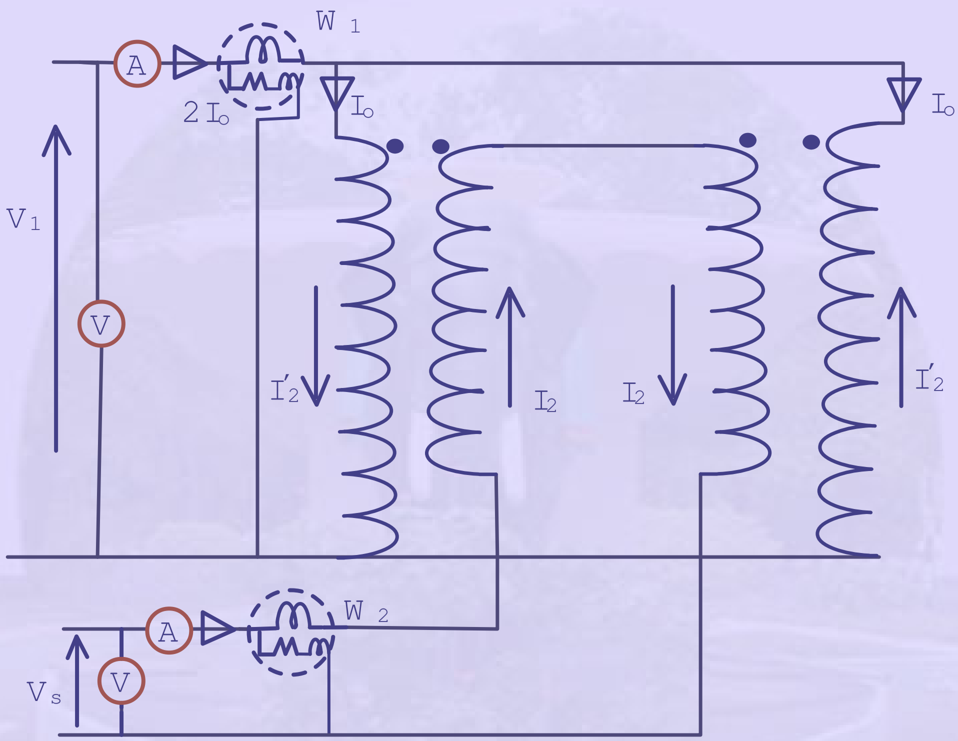


Figure 22: Back to Back Test - Phantom Loading

In Phantom loading method two identical transformers are needed. The windings are connected back to back as shown in Fig. 22. Suitable voltage is injected into the loop formed by the two secondaries such that full load current passes through them. An equivalent current then passes through the primary also. The voltage source V1 supplies the magnetizing current and core losses for the two transformers. The second source supplies the load component of the current and losses due to the same. There is no power wasted in a load (as a matter of fact there is no real load at all) and hence the name Phantom or virtual loading. The power absorbed by the second transformer which acts as a load is pushed back in to the mains. The two sources put together meet the core and copper losses of the two transformers. The transformers work with full flux drawing full load currents and hence are closest to the actual loading condition with a physical load.