

# Application Note

## Why Do We Measure Transformer Winding Resistance

Winding resistance measurements in transformers are of fundamental importance for the following purposes:

- Calculations of the  $I^2R$  component of conductor losses.
- Calculation of winding temperature at the end of a temperature test cycle.
- As a base for assessing possible damage in the field.

Transformers are subject to vibration. Problems or faults occur due to poor design, assembly, handling, poor environments, overloading or poor maintenance. Measuring the resistance of the windings assures that the connections are correct and the resistance measurement indicates that there are no severe mismatches or opens. Many transformers have taps built into them. These taps allow ratio to be increased or decreased by fractions of a percent. Any of the ratio changes involve a mechanical movement of a contact from one position to another. These tap changes will also be checked during a winding resistance test.

Regardless of the configuration (either wye or delta), the measurements are made phase to phase. Comparisons are made to determine if the readings are comparable. The purpose of the test is to check for gross differences between the windings and for opens in the connections. The tests are not made to duplicate the readings of the manufactured device which was tested in the factory under controlled conditions and perhaps at other temperatures.

## Transformer Characteristics

A transformer is a passive device capable of storing and delivering finite amounts of energy. All transformers utilize magnetic material for shaping the magnetic fields which act as the medium for transferring the energy. The relationship between the magnetic field and the electric circuits with which it interacts plays an important part in describing the operation of the device. The magnetic material determines the size of the equipment, its capability, and introduces limitations due to saturation and loss on the performance.

A transformer consists of two or more windings interlinked by a mutual magnetic field. These windings are coils of wires, inductors. Transformer characteristics can now be analyzed using simple formulas. The voltage across an inductor is proportional to the time rate of change of the current through it.

$$V = L \, di/dt$$

It should also be noted that an abrupt change in inductor current also requires an abrupt change in the energy stored in the inductor, and this sudden change in energy requires infinite power at that instant;

infinite power does not exist in real-world applications. The inductor current must not be allowed to jump instantaneously from one value to another. If an attempt is made to open-circuit a physical inductor through which a finite current is flowing, an arc will appear across the switch. This is useful in the ignition system of an automobile, but not something anyone wants to witness during testing of the transformer windings.

The energy stored in an inductor with a circulating current can be represented by the formula:

$$W(t) = 1/2 I^2 L,$$

where,

**w(t)** = Energy as a function of time,

**I** = Current in amperes,

**L** = Inductance in Henries

Before the desired test current can flow through the winding, this energy requirement must be met. This implies that some time requirement will also be necessary before the measurement can be made. This time requirement applies only to the charging time. Additional time must be allowed to stabilize the current before a measurement can be made.

The total time required to make a reading is limited by an inherent time lag between the application of a steady current and the moment the magnetization of the core becomes stable. Depending on the size and the construction of the transformer, testing times can be very short for small transformers or very long for the larger, highly inductive transformers.

## Testing Equipment

Prior to modern digital electronic equipment, the Kelvin Bridge was used. Batteries, switches, galvanometers, ammeters and slide-wire adjustments were used to obtain resistance measurements. Current regulators were constructed and inserted between the battery and the bridge. The input voltage to the regulator of 12 V DC from an automobile storage battery provided output currents variable in steps which matched the maximum current rating of the bridge on the ranges most used on transformers. The current regulator increased both the speed and accuracy of the bridge readings. The approximate 11 V availability was used to speed up the initial current buildup and tapered off to about 5 V just before the selected current was reached and regulation started.

When the regulation began, the current was essentially constant in spite of the inductance of the windings and fluctuation of the battery voltage or lead resistance.

The testing times have been greatly reduced by using modern microprocessor-based test instruments. Direct readings are available from digital meters with automatic indications showing when a good measurement is available. On some testers, two measurement channels are available allowing for two resistance measurements at the same time.

**Caution:** Because of the enormous amount of energy that can be stored in a magnetic field,

precautions should be taken before disconnecting the test leads from the transformer that is under test. Never remove the leads during the testing process and always allow for enough time to completely discharge the transformer being tested. Large transformers can require several minutes to discharge. Most new winding resistance testers today have indicators which show when it is safe to remove the leads.

## Principles of Operation

The basic idea is to inject a DC current through the winding to be measured, and then read the voltage drop across that winding.

Electrical testing instruments apply the DC current through the winding and an internal standard current shunt. After both DC voltage drops are measured, the resistance calculation is performed and its value is displayed on the instrument front panel. This method allows for the lead resistance to be omitted since the reading is independent of the current. In addition, no multiplication factors will be needed when changing current ranges.

The DC current source must be extremely stable. The formula for DC voltage across a transformer is given below:

$$V = I * R + (L \, di/dt)$$

where,

**V** = voltage across transformer winding

**I** = DC current through transformer winding

**R** = resistance of the transformer winding

**L** = inductance of the transformer winding

**di/dt** = changing value of current (ripple)

Assuming that the tester has a very stable current source (i.e., no ripple), then **di/dt** is zero and the **L di/dt** becomes zero.

## Tap Changers

Tap changers are divided into two types: On-load and Off-load. The on-load tap changer allows changing the turns ratio while the transformer is in service. This would mean the ratio of a transformer can be changed while power is still passing through it. The most common example of this type of on-load tap changer is a Voltage Regulator.

## On-Load Tap Changer

When testing on-load tap changers, the instrument needs to be left on while changing from tap to tap. This allows the operator to take measurements very quickly without discharging, then re-charging the transformer for every tap. The winding resistance tester must rebalance after every tap change.

If the tap is defective (open) or if there is even a fraction of time when the circuit is open, the winding resistance tester will automatically go into its discharge cycle. This gives the operator a clear indication of a possible fault within the tap changer. For this open circuit condition, no damage will be done to the transformer by the test set.

## De-energized Tap changer

This type of tap changer requires that the tap changer must be discharged between tap changes. In order to change taps, the transformer has to be taken out of service.

The resistance tester will still work on this changer but the measurement must be stopped and restarted between tap changes.

## Safety

Although some transformer diagnostic may be accomplished without de-energizing the transformer, the winding resistance measurement is not one of them. To provide maximum safety to the worker, both the high-voltage and low-voltage leads should be disconnected from the transformer. Preferably, there should be a visible break between the transformer terminals and the high and low voltage lines.

The winding resistance measurement instrument must be properly grounded during the test. It is also recommended to ground one side of the tested winding during the measurement.

## Conclusion

Transformers are very reliable devices which can provide service for a long time if maintained and serviced regularly. Transformer failures, when they occur, are usually of a very serious nature, which may require costly repairs and long downtime. The best insurance against transformer failure is to ensure that they are properly installed and maintained.

Make sure that the winding resistance test is included when a transformer is tested. Keep good records on the values of resistance found and compare them with previous readings for deviations.

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