Application Note - Winding Resistance Measurements

Winding resistance measurements in transformers are of fundamental importance for the following purposes:
- Calculations of the I2R 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, handing, 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 and comparisons are made to determine if the readings are comparable. If all readings are within one percent of each other, then they are acceptable. Keep in mind that 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 considered a passive device capable of storing and delivering finite amounts of energy. Practically all transformers utilize magnetic material for shaping the magnetic fields which act as the medium for transferring energy. The relationship between the magnetic-field quantities and the electric circuits with which they interact 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 because of saturation and loss on the performance.

Essentially, a transformer consists of two or more windings interlinked by a mutual magnetic field. These windings are simply coils of wires, inductors. Transformer characteristics can now be analyzed using some 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 is not part of the real world. 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 hardly an event to be witnessed during testing of the windings in the transformer.

The energy stored in an inductor with a circulating current can be represented by the formula:
w (t) = 1/2 I2L where,
w(t) = Energy as a function of time
I = Current in amperes
L = Inductance in Henries

Before the desired current will flow (for testing purposes), this energy requirement must be met and 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 ultimate time required to make a reading is limited by an inherent time lag between the application of a steady current and the time the magnetization of the core becomes stable. Depending on the size and the construction of the transformer, testing times could 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 slidewire adjustments were used to obtain resistance measurements. Current regulators were constructed and inserted between the battery and the bridge. Input voltage to the regulator of 12 volts 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 speed and accuracy of the bridge readings. The approximate 11 volt availability was used to speed up the initial current buildup and tapered off to about 5 volts 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 using modern microprocessor based test equipment. Direct readings are available from digital meters with automatic indications telling when a good measurement is available. On some testers, two meters are available allowing 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 telling 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 they are ratioed and the display is read as resistance on the front panel meter. 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. Refer to formula for DC voltage across a transformer below:
$v = I * R + (L\, di/dt)$where,
vdc = 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)

Assume that the tester has a very stable current source (i.e., no ripple), then di/dt is zero and the term 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 section of ratio change 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 need 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 by a panel light of a possible fault within the tap changer. For this open condition, no damage will be done to the transformer by the test set.

Off-Load Tap Changer
This style 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 or at least disconnected from the load. This type of tap changer may typically go bad faster than an on-load because of inadvertent changing of the taps while still in service.

The resistance tester will still work on this changer but it must be discharged between tap changes.

Safety
Although some items of inspection 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.

Conclusion
Transformers are very reliable devices and 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. Modern self-contained instruments make testing easy and accurate.

Keep good records on the values of resistance found and compare them with previous readings for deviations.

Source: Electricity Today