TRANSFORMERS, THEIR TESTING AND MAINTENANCE

Transformers are the most proliferated piece of equipment on any power system. The reason for this is that the generated power typically needs to be stepped up to the transmission network, then it needs to be stepped down to the distribution network, then it needs to be stepped down again to feed customers at the service voltage. Assuming the above arrangement to be reasonably accurate, the capacity of transformers on any power system would be typically 3 times larger than its peak demand. Thus the total transformer capacity in Canada is expected to be about 400,000 MVA, for a installed generation of 125,000 MVA. This MVA accounts for a large number of transformers.

With this large number of transformers to contend with, one might imagine that there would be a lot of maintenance and repair associated with keeping them in service. This is not exactly the case because most transformers are very efficient (the large ones may be 99.9% efficient) and reliable due to the absence of moving parts (except for auxiliaries such as cooling fans and oil pumps). In addition to proper design and construction, it is the exhaustive testing that a transformer is subjected to that helps to keep them in service for many, many years. Many of these tests are conducted during its manufacture, or immediately upon completion. Others may be done during the service life, and are a part of maintenance procedures that are designed to discover any malfunctions that may be instrumental in shortening the normal long life of transformers.

Discussed below will be the test that can be performed on a power transformer during its performance or maintenance testing. The tests are given in a random order.

DIELECTRIC OR INSULATION TESTS.

The dielectric tests consists of power frequency and impulse testing that are designed to prove the integrity of the insulation systems in the transformer.

Applied Potential Tests.

In this power frequency test, a high voltage of prescribed magnitude is applied between windings, or between windings and ground. The test is of short duration (1 minute) and many manufacturers use this test also to test the power factor of the insulation. The test requires a metered power supply of suitable rating. Pass or failure of the test is typically determined from the noise, emanating from the transformer, or from the readings of the voltmeter and ammeter for the test source. Those who use this test to measure the capacitance and power factor of the tested insulation, also require a capacitance bridge and a standard capacitor of suitable rating. The bridge readings are typically taken at ¼, ½, and rated voltage of the transformer, as well as at the applied potential test (highpot) voltage. Stability of the capacitance and especially the power factor, over the above voltage range indicate a sound insulation system. In most of the factories partial discharge equipment is connected to one or all of the bushings during this test. An increase in partial discharge always precedes any failure, and therefore the partial discharge profile with voltage is also a good indication of insulation quality.

Induced Potential Test.

The induced potential test is designed to stress the turn-to-turn insulation of the transformer. In order not to saturate the core, frequencies of 120 to 400 cycles are used. The test duration depends on the frequency used, and requires only a suitable metered power supply.

Impulse Tests.

Impulse tests are divided into full wave, chopped wave, and switching surge. The magnitude, polarity, and the number of applications of any of these is governed by specifications of the insulation level. For one to be able to do impulse testing, he requires a surge generator of the correct voltage rating and capacity. One must also be equipped with auxiliary components to be able to configure the desired impulse shape. This typically requires load capacitor, shaping resistors, and a chopping gap.

The pass or failure of a specimen is done by means of comparing photographs of the voltage and/or current waveforms. Lately, equipment capable of digitally recording these waveforms has become available, and such waveforms can be compared on CRT screens or even by computers.

Insulation Power Factor Test.

Power factor testing of the insulation was already mentioned earlier under the applied potential test. In addition to the above tests, many manufacturers test every segment of insulation, including bushings, by means of a dedicated 10, or 2.5 KV power factor test. These measurements become the starting points of the power factor history for the transformer insulation, as these measurements can, and frequently are, repeated annually during the life of the transformer. Measurements using low voltage bridges operating at other than the power frequency are equally acceptable for monitoring the power factor of the insulation. These instruments are capable of filtering out the power frequency interference present in the field, and can make a meaningful measurement using only 20-30 volts.

PERFORMANCE TESTS.

The performance tests are tests that give the utility information regarding the behaviour of the transformer under system operating conditions. This includes such items as losses, and impedance.

Open Circuit Test.

The open circuit test consists of measuring the exciting current and power the transformer draws on open circuit, when excited with rated voltage. This test is conducted in a three-phase configuration for a three-phase transformer. One requires a suitable supply, as well as facility to measure voltage, current, and power to high accuracy. As the voltage may be anywhere from 120 volts to hundreds of kilovolts, and the current from a fraction of an ampere to perhaps hundreds of amperes, the metering set-up must include voltage and current transformers of the required ratios in addition to voltmeters, ammeters, and wattmeters.

Available commercially, are also "Metering Systems" which feature a complete three-phase measuring arrangement. These systems are very versatile, in that they operate with high accuracy over a 100 to 1 range of voltage, and 1000 to 1 range of current. Being electronic, some of these systems can take simultaneous readings of all three phase values, display them for the operator, or send them to a computer for further analysis.

It is important to point out here, that most measurements on transformers require the measurement of average, or flux voltage, in addition to the rms voltage. These measurements are necessary for the calculations of corrections specified by national or international standards.

Short Circuit Test.

The short circuit test gives the utility information on the impedance and load, or copper losses of the transformer. The test set-up and equipment are very similar to that required for the open circuit test, but the range of voltages has been reduced, and the range of current increased.

It is important to point out here that the transformer impedance is typically resistive for small transformers, changing to mostly inductive for very large transformers. The measurement of copper losses, therefore, on very large transformers is very difficult due to the low power factor of the circuit (typically as low as 0.01). Any metering equipment used for this application must exhibit very high accuracy with respect to phase, for an error of only 1 minute in phase can result in an error of 3% in power at this low power factor.

Heat Runs.

Most transformers are subjected to a heat run, where the manufacturer substantiates the transformer's losses and temperature rise to his customer. The heat run is conducted using the short circuit test, as the copper losses for the bulk of the transformer losses. In addition to measuring the power input, there is a need to measure oil and other temperatures on the transformer.

The average temperature rise of the winding, which is limited by the insulation used, is determined by means of measuring the average resistance increase of that winding. This measurement is discussed later under resistance measurement.

OTHER TESTS.

There are a variety of tests that are done in addition to the main ones discussed above. The term "other" is not to signify their insignificant, for the ratio, polarity, and others are just as, or even more important than insulation, impedance or losses.

Ratio.

One of the first members to be specified in the ratio of the required transformer. The tolerance for ratio of distribution transformers is ±0.5%, and this number is typically accepted for all power transformers. The ratio can be measured during the open circuit test, but it is much more convenient to use a dedicated ratiometer that operates on reduced voltage. Such transformer ratiometers are available in a variety of configurations, including - manual or auto-balancing; single phase or three phase switching arrangement types.

A ratiometer test will in all cases also determine the polarity of the transformer.

Polarity.

The polarity of a transformer must be known in order to determine its proper connection in the power circuit. Ratiometers confirm the polarity of transformers, but dedicate polarity instruments are commercially available. Most of these work on the "kick-back" principle, where the application of a voltage causes an upscale reading of a meter, and the removal of the voltage causes a downscale reading.

Resistance.

The dc resistance of windings is very important in that it is used in the following determination:

- calculation of I^2R losses.
- calculation of temperature rise.
- determination of winding damage.

Although most would consider the measurement of resistance to be a trivial measurement, measurement of dc resistance in the presence of large inductance is a real challenge.

There are three problems involved here. One is to overcome the initial inductance of the core and winding. This is typically done by applying sufficient volt-seconds to partially, or completely saturate the core. The volt seconds required depend on the voltage rating of the winding being measured. THe second problem is to stabilize the test current sufficiently so that a measurement can be taken. It must be remembered that the winding inductance multiplied by the rate of change of current appears as a resistance. It can be shown that even small rates-of-change of test current, will result in substantial errors in dc resistance measurement under certain conditions.

The last problem is to absorb all the energy that has been accumulated in the inductance of the winding and core of the transformer. This energy must be allowed the discharge slowly. If abrupt changes are introduced, such as an open circuit, dangerous and possible damaging voltages may appear across all windings of the transformer.

Traditionally, wheatstone or kelvin bridges have been used for winding resistance measurement. These have been replaced by electronic instruments that work on the voltmeter-ammeter principle. Modern electronic instruments will feature a reasonably high voltage to overcome the volt seconds of high voltage windings. They will also have circuitry that will absorb the energy stored in the transformer at the end of the test. Operating on the voltmeter-ammeter principle, such instruments can measure two or even more windings at the same time. The feature reduces the number of set-ups required to measure all the windings in any transformer. As mentioned earlier, the winging resistance is important because it is used to calculate the stray losses in the short circuit test. These are the differences between the measured losses and the calculated I^2R losses.

Since the test is reasonably simple to conduct in the field with proper equipment, the measurement of winding resistance, when corrected to a reference temperature, is a good sign of winding damage.

OIL TESTS.

One can not imagine conducting tests on a power transformer without subjecting its insulating oil to a series of tests at the same time. Testing of insulating oil is a large subject in itself, and may include electrical, physical and chemical tests. The more prevalent tests on insulating oil include:

- breakdown
- resistivity
- power factor
- dissolved gases
- interfacial tension
- water in oil

Some, or all, of these tests may be conducted on oil prior to filling the transformer, after or during the final tests, or during the service life of the transformer. Most of these tests are conducted in a laboratory using samples drawn from the transformer. Some of these, like breakdown and powerfactor, may be done in the field using portable test equipment.

The test results from periodic tests on oil are a good indication of the transformer's condition, and outlook for continued service. Problems inside the transformer can at times be identified by the results of such test and remedial action planned accordingly.