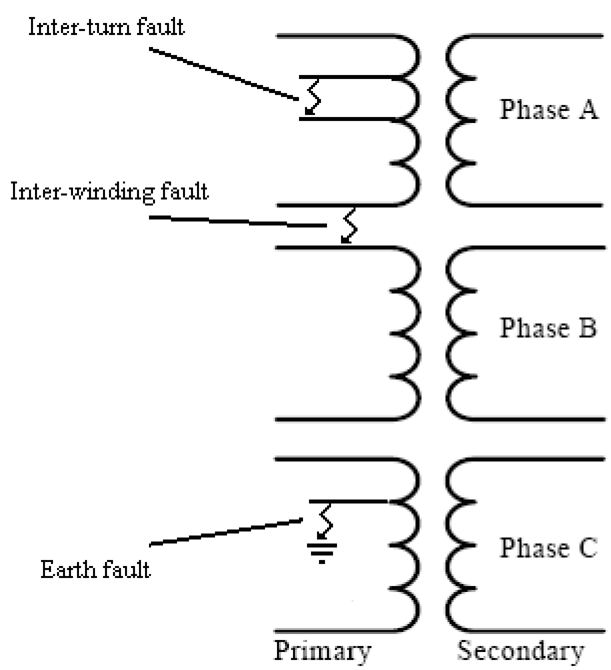
Dry-Type Transformer Testing

Introduction

The primary concern with all transformers (and also the key indicator of life expectancy) is the condition of the insulation system.

For dry type transformers, the insulation system consists of the cast resin winding and core insulation and the termination system insulation (e.g. bushings). The structural strength and insulating properties of materials used for these insulation systems degrade over time through normal ageing. They can also degrade prematurely as a result of overheating and mechanical and electrical stresses (e.g. faults, overvoltages, inrush currents, etc).

The initial breakdown of insulation around the windings can result in inter-turn faults, especially on the high voltage windings where the electric field strength is high enough to ionise air gaps and cause corona activity. Inter-turn faults are short circuits between coil turns on a single winding. Further degradation of the insulation could see inter-turn faults develop into more serious faults such as inter-winding and earth faults.



Testing

The most frequent mode of failure for dry type transformers is insulation breakdown resulting in inter-turn faults which leads to more severe faults such as phase to phase winding or earth faults. The insulation condition of component parts of the transformer (i.e. windings, core, bushings, etc) can be determined by a suite of tests.

Dissolved gas analysis is the most commonly used method for determining winding insulation condition in oil-type transformers, but is not possible for dry-type transformers.

The following tests are discussed further:

- Insulation resistance / polarisation index tests
- Dielectric loss angle measurement tests
- Partial discharge tests
- Frequency response analysis
- Acoustic emission tests (in conjunction with partial discharge tests)
- Thermographic surveys

Insulation Resistance Tests

Insulation resistance, measured by application of an impressed DC voltage (i.e. Megger), gives a general indication of the insulation condition between the phase windings and earth. The measurements are typically taken over time (i.e. 1 minute intervals over 10 minutes) to generate a curve, called the Dielectric Absorption curve.

The Polarisation Index is the steepness of the curve at a given temperature and is defined as per the following equation [1]:

$$PI = \frac{R_{10}}{R_1}$$

Where

R_{10} = megohms insulation resistance at 10 minutes

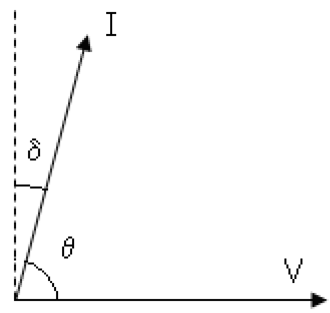
R_1 = megohms insulation resistance at 1 minute

The Polarisation Index indicates the relative dryness and level of moisture ingress into the insulation.

Dielectric Loss Angle Measurement Tests

Dielectric loss angle tests, also called dissipation factor, power factor or tan delta tests, determine the insulation dielectric power loss by measurement of the power angle between an applied AC voltage and the resultant current. In the ideal insulator, the power angle would be 90°C as it is purely capacitive and non-conducting. However in real insulators, there is some leakage current and resistive losses through the dielectric.

Relative increases in dielectric power losses are indicative of insulation deterioration and may further accelerate degradation due to increased heating. Note that dielectric power loss does not translate to dielectric strength, though there are often common causes for increases in power loss and decreases in dielectric strength.



The cosine of the power angle (θ) is called the power factor. The complement of θ is denoted δ as shown in the diagram above. The power factor can be practically approximated by taking the tangent of δ (hence the name tan delta). This approximation is called the dissipation factor and is roughly equal to the power factor between values of 0 and 0.08, which covers the majority of tests.

The dissipation factor is essentially the ratio between the resistive and capacitive components of the insulation and can be measured directly (via a capacitance bridge circuit). The lower the quality of the insulation condition, the more resistive it will appear and the more power loss will be dissipated through it (in the form of heat).

The increase in the dissipation factor values as the test voltage is increased is called the "tip-up".

The technical literature on this subject has noted that this test is useful for detecting moisture ingress in the bushings and windings. About 90% of bushing failures may be attributed to moisture ingress evidenced by an increasing power factor from dielectric loss angle testing on a scheduled basis.

Partial Discharge Tests

Partial discharges are localised incipient electrical discharges that only partially bridge the insulation between conductors. Partial discharges can occur in any location where the local electrical field strength is sufficient to breakdown that portion of the dielectric material (whether it be deteriorated insulation or air). In dry-type transformers they can occur within air-filled voids where the solid insulation has degraded.

Partial discharge testing can detect the presence and location of partial discharge activity in a transformer. Partial discharges in transformers are typically measured by applying a pre-specified voltage to the transformer windings and measuring induced charges via a coupling device (e.g. coupling capacitors).

AS 60076.11 and AS 60270 set out the requirements, procedure, equipment and acceptance levels for partial discharge testing [3] [4]. It should be noted that the partial discharge tests specified in AS 60076.11 are intended as routine tests for new transformers. This involves applying a “pre-stress” voltage of 1.8 times rated voltage to the windings. This may be excessive for transformers already in service for over 20 years.

Analysis of the partial discharge measurements gathered (i.e. pulse waveforms, magnitude, duration and intervals between pulses) can be used as a guide regarding the condition of the insulation. The results can be trended to chart the rate of insulation degradation between consecutive tests.

Frequency Response Analysis

Frequency response analysis is a diagnostic testing technique that measures the impedance of the transformer windings over a wide range of frequencies. The measurements are compared with a reference set and the differences are highlighted. The differences may indicate mechanical damage to the windings (e.g. winding displacement or loose winding) and electrical faults (e.g. interturn faults).

Frequency response analysis can be achieved by either injecting a low voltage impulse into the winding (i.e. impulse response method) or by making a frequency sweep using a sinusoidal signal (i.e. swept frequency method).

For frequency response analysis to be useful, a baseline reference set of measurements need to be determined and periodic tests need to be conducted to compare the differences.

Refer to research by S. Tenbohlen et al at the University of Stuttgart [5].

Acoustic Emission Tests

Partial discharges in transformers can also be detected and localised via acoustic emission testing. Acoustic emission testing is based on the acoustic detection of the partial discharge pulses and conversion to an electrical signal. Sensors are coupled to the surface of the transformer and during operation of the transformer, the output of the sensors are fed into an electronic module. The signals are filtered to remove noise and processed to determine the presence and location of any partial discharges in the transformer.

Thermographic Surveys

Infrared thermography is commonly used in preventative maintenance to detect hotspots, especially at joints and terminations. IR Thermography cameras measure surface temperatures and the resulting thermal image can be used to identify overheating at the transformer terminations.

For thermographic surveys to be conducted, thermographic windows need to be installed looking at the terminations and windings.

References

1. Facilities Instruction, Standards and Techniques Volume 3-1, “Testing Solid Insulation of Electrical Equipment”, U.S Department of the Interior, Reclamation Branch, December 1991
2. Facilities Instruction, Standards and Techniques Volume 3-31, “Transformer Diagnostics”, U.S Department of the Interior, Reclamation Branch, June 2003
3. AS 60076.11, “Power transformers Part 11: Dry-type transformers”, 2006
4. AS 60270, “High-voltage test techniques – Partial discharge measurements”, 2001
5. Research at University of Stuttgart (including Tenbohlen's papers)

Source:

http://www.openelectrical.org/wiki/index.php?title=Dry-Type_Transformer_Testing