Diagnostic Methods for the Maintenance of Power Transformers

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Abstract: The maintenance of electric power equipment is a statutory regulation. The asset manager of electric power networks or power stations has to decide on the optimal maintenance strategy, normally the condition based is applied. For the condition determination different technical diagnostic methods were used. In this paper the stat of the art of the oil analysis, dielectric response measurements as well as partial discharge detection is discussed. Additionally innovative methods as optical PD detection or thermal imaging by IR-cameras were shown.

Keywords: Transformer, Technical Diagnosis, Maintenance, Oil Analysis

Introduction

Power transformers are one of the most important but also expensive components of the electrical power supply. An unexpected outage results in substantial costs mainly caused by the outage of the power station. Therefore a huge interest for monitoring and diagnosis systems to evaluate the condition of the transformer is given. Different on-line and off-line monitoring systems are in use.
The most common insulating system for transformer is the oil-board insulating system. The oil and the board are organic components and underlie aging, which depends mainly to the operating condition. Deterioration processes relating to aging are accelerated by voltage and thermal stresses.
A defect in transformers can be caused by electrical, electromagnetic, dielectric, mechanical, thermal and/or chemical load (stress). The typical failure distribution of high voltage transformer shows that the highest risk for failure are the tap changer, windings and the core as well as the bushings.
For a check of the transformer condition, different diagnostic methods are available and use chemical, mechanical, optical, thermal and electrical methods.

1. CHEMICAL DIAGNOSTIC METHODS

Because of the development of new sensors with higher sensitivity the chemical methods become more important. For example, the most efficient tool for the recognition and classification of thermal and electrical failure is the Dissolved Gas Analysis (DGA).

In most cases by using chemical methods (Fig. 1), it is possible to verify failure, which has changed since the last measurements, but it is not possible to say something about the exact failure or the date of origin.

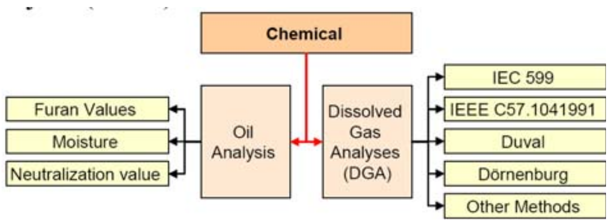

Figure 1: Chemical Oil Analysis

1.1 Chemical Physical Analysis

Measuring the chemical and physical properties of transformer oil a number of conditions associated either the oil or the solid insulation system can be determined. The following parameters were some of the most common tests performed on electrical insulating oils:

Moisture Content: The increase of the moisture in oil reduces the insulating quality of the oil. Normally the moisture is determined by the Karl-Fischer Titration method.
Acid Number: Under the influence of temperature and oxygen as well as under the presence of small metallic particles as catalysts the acid number increases. Under the formation of carboxylic acids the oil further reacts under deterioration of the cellulose paper.
Dielectric Strength: A significant reduction of the breakdown voltage indicates a poor oil condition. The oil has to be dried, regenerated or replaced.
Dielectric Dissipation Factor: The DDF (tan δ) is the ratio of the true to the apparent power of the dielectric losses. It is an indicator for significant power losses in the insulating oil. A high tan δ usually results from polar contaminations such as water, oxidized oil and cellulose paper degradation.

1.2 Dissolved Gas Analysis

An important feature for condition assessment of power transformer is the gas-in-oil analysis. If partial discharge, overheating, hot spots or local breakdown inside the transformer occur, several gases are produced and dissolved in the oil. Such failures produce hydrogen, oxygen, nitrogen and lower-molecular hydrocarbon compounds as methane, ethane, carbon monoxide or carbon dioxide. In addition to the concentration of various gases are the ratio of some gases to each other for a failure diagnosis of great importance. Beside periodically performed gas-in-oil analysis in the last years, new systems with sensors for on-line detection have been developed. The continuous gas-in-oil monitoring may detect the start of incipient failure conditions to allow confirmation of a suspected fault.

2. ELECTRICAL DIAGNOSTIC METHODS

For the detection of a failure, different measurement technique are in use. Figure 2 shows an overview about the common methods.

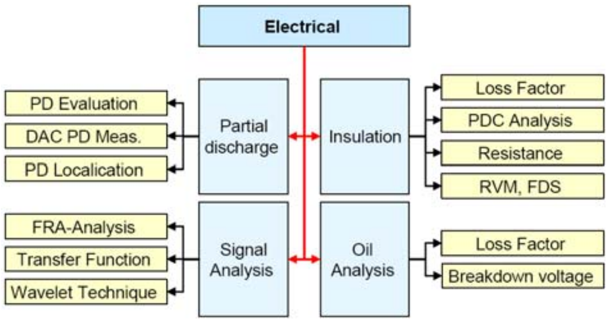

Figure 2: Electrical Diagnosis

The measurement and evaluation of the 'dielectric response' is one possible way of diagnosing a transformer's insulation condition. Moisture and ageing strongly influence the dielectric properties of oil/cellulose insulation systems. The resistance measurement of all coils on all steppings can show conclusions about turn-to-turn fault or breaks. The most famous and popular electrical diagnostic method for evaluating of the oil condition is the oil breakdown voltage. This method is standardized and delivers the resistibility of the oil against alternating voltage.

2.1 Partial Discharge (PD)

The PD measurement is an important method to detect and locate a weak spot in the insulation system. The partial discharge activity is the most prominent indicator for insulation degradation. For example they occur in transformer in gas bubbles in the oil, voids in solid insulation material or at metallic particles. Partial discharges have only a “short time effect” on the electrical firmness of electrical resources. On the other side the long time influence shows a destructive effect predominantly on organic insulation systems, which degrade the electrical characteristics of the insulation or the insulation systems. A significant increase of the PD level or the rate of the PD can provide an early indication for some evolving of defects. The PD pulses generate electromagnetic waves, acoustic signals, chemical reactions, local heating and optical signals. So different techniques can be used to detect these phenomena. For the detection different types of sensors were used, for example high frequency current transformer, bushing capacitive taps, piezoelectric sensors.

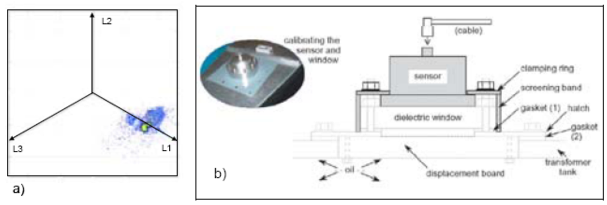

Figure 3: a) PD evaluation with 3-phase amplitude diagram (3PARD) and b) UHF window retrofitted to a transformer inspection hatch [5]

The measurement according to the IEC 60270 is a useful tool for laboratory measurement because it is a sensitive method and can be calibrated, but on-site measurements can be affected by disturbances. Some signal processing methods have been used to suppress unwanted noise. For example, time filtering suppresses periodic and regular net synchronous disturbances, frequency filtering, noise suppression by trained neural networks [4]. Another possibility is the measurements at frequencies where the S/N level is maximal - VHF and UHF PD measurement (Fig. 3b).

The acoustic partial discharge measurement uses the fact, that an acoustic signal (mechanical vibration) as a result of the pressure build-up caused by a generated discharge in the insulation medium is emitted. Because of the short duration of the PD-impulses, the resulting compression wave has frequencies far in excess of the audible band of sound. The frequency spectrum lies in the range between 10Hz up to 300kHz. In transformer, mechanical waves generated by PD propagate though the oil, hitting the tank walls where the sensors (Piezoelectric sensors) for the acoustic signal detection are fixed externally. Beyond the electromagnetic wave emissions, each partial discharge emits radiation. This emission transports information about the energy level of the discharges. In connection with the electrical discharge, a radiation in the ultraviolet-, visible and infrared area could be recognized. The emission spectrum of partial discharge in liquids contains components characteristic of the insulating material or of its chemical components. For the measurement different optical sensors and techniques can be used [6].

2.2 Response Analysis

Depending on the type of application different methods - Impulse Response Analysis (IRA), Step Response Analysis (SRA) and Frequency Response Analysis (FRA) - are used. The FRA is primarily used for detection of deformation or movements of windings. Thereby a HF signal is applied and the corresponding winding responses are recorded. The measurement of the current and the voltage during the impulse test allows the calculation of the impedance or its reciprocal value as function of the frequency (transfer function). The function describes the transformer behaviour independent on the input signal.

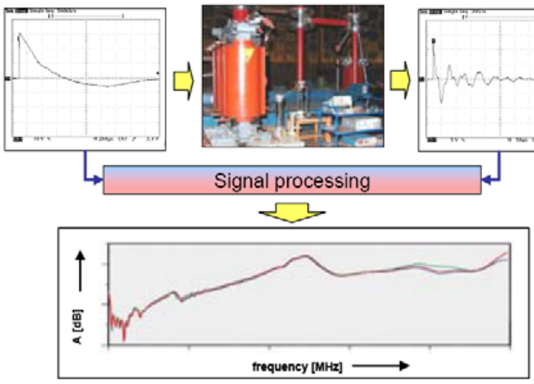

Figure 4. Transfer function describes a transformer as an electric network

For On-site measurement it is possible to generate the transfer function by switching operations or by measurement of lightning or switching impulse voltages and currents. Different methods to measure the low frequency response of power transformer are used. The swept frequency method makes use of a simple truth that the sinusoidal AC impedance of a transformer winding varies with frequency over the range of interest. Another method is to use a low voltage impulse for the measurement and calculated by an Fourier analysis. The transfer function is calculated as the FFT of the output divided by the FFT of the input (fig. 4). Modern techniques work on the basis of the low voltage impulse method with high speed, high resolution and sensitive analyzer with a superior signal to noise performance at high frequencies. The calculation for the transfer function is done by a series of impulses (an average frequency domain spectral density estimate is computed – transfer function calculation as ratio of the average cross spectra to the average auto spectra) [10].

2.3 Polarization and Depolarization Current Analysis (PDC)

The PDC analysis is a non-destructive dielectric testing method for determining the conductivity and moisture content (insulation humidity) of insulation materials in a transformer. Polarization and depolarization currents are influenced by the properties of the insulating materials as well as the geometric structure of the insulating system. For the measurement a DC voltage step is used for a specific polarization time. During this time a pulse-like current flows and falls to a constant value depending on the conductivity of the dielectric. After the polarization time the voltage is removed and the dielectric is short circuited via the amperemeter. The discharging current jumps to a negative value, which goes towards zero. After this, a model for the transformer main insulating system which describes its dielectric behaviour is assigned. All parameters for the dielectric model can be calculated from the polarization characteristics of material samples of precisely specified moisture content, the geometry of the main insulation and the positions of the samples. As a result, information about the moisture content, tanδ, the conductivity of the oil and the polarization index of the insulation system can be obtained.

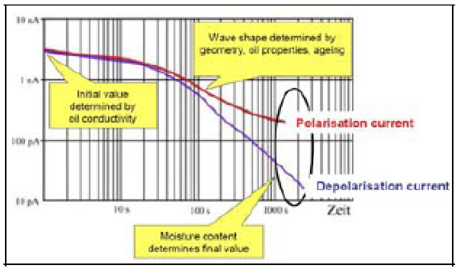

Figure 5. PDC measurement of a transformer winding according [7]

The recovery voltage method (RVM) is another time domain method used to investigate slow polarization processes.

3. THERMAL/OPTICAL DIAGNOSTIC METHODS

Both thermal and optical diagnostic methods are using the electromagnetic spectrum between 104Hz up to 1016Hz as information source.

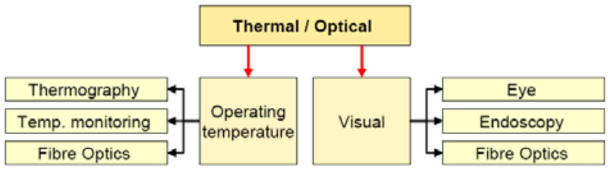

Figure 6. Thermal/Optical diagnostic methods

3.1 Temperature measurement

Temperature measurement will identify potential problem areas (hot spots) that can lead to substantial equipment damage. Of great importance is the maximum temperature because according to a simple model for thermal aging, an "aging rate" can be defined. This aging rate doubles with approximately 6K temperature rise. The measuring of the oil temperature and the load current allows an indirect calculation of the hot spot inside the transformer. So the correlation between temperature, load and ambient conditions would allow the detection of abnormal condition and on the other side the optimal use of the equipment (load limit). Several principles have been used for measuring the temperature. For example, temperature measurement using Pt100 sensors or thermocouple devices, fibre optic systems for single point, fibre optic systems for distributed measurement and infrared temperature measurement. The contact-afflicted temperature measurement, the measuring sensor is brought in thermal contact with the measuring surface. Contact temperature sensors measure their own temperature, so the test object and the sensor must be in thermal equilibrium. For an on-line monitoring system thermocouples are placed at various locations on the transformer. Mathematical models have been used to accurately predict oil and winding temperature for varying conditions, using exclusively external thermal detectors. Another possibility is the use of fibre optic temperature sensors. To take into account, however, is, that they are already must be installed during the transformer manufacture. Two different sensor types are available. The measurement of the temperature with the optical fibre in one point, or measure the temperature along the length of the fibre (Raman effect).

3.2 Thermography

For surfaces, infrared thermography based technologies can be used.

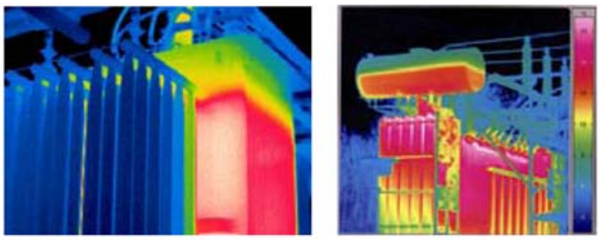

Figure 7. Thermography of a transformer [8]

The spectrum and the intensity of infrared radiation from the object is a function of its temperature. Each body – whose surface temperature deviates from the absolute zero – emits electromagnetic waves and these emitted waves with their different wavelength and intensity spectra can be used for temperature measurement. For detecting thermal problems in a transformer, such as cooling system blockages, locating electrical connection problems, and for locating hot spots thermograpy is a useful method.

3.3 Optical measurement

The best optical diagnostic method is the human (eye) inspection. Endoscopes allow the optical investigation of parts inside of the transformer. With this method, the observation of abrasion and burnout guises of the tap changer of the transformer is possible.

4. MECHANICAL DIAGNOSTIC METHODS

The tension force decreases during operation so a monitoring is useful for transformers where the risk of short circuit is high. To determinate the existing tension force is the measurement of the transient oil pressure after applying of a current surge. Another mechanical diagnostic method is the stream analysis for controlling the cooling system.

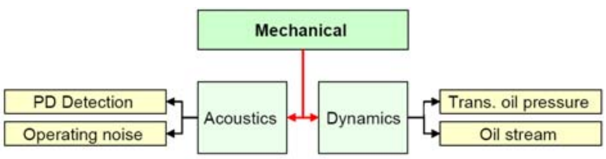

Figure 8. Mechanical diagnostic methods

A further possibility is to analyze the acoustic vibration signal for a transformer. Some investigations show that the emitted acoustic spectrum of a transformer is characteristic for types of a defect. The acoustic vibrations of a transformer can be generated for example by the coil vibrations depending on the current amplitude and winding clamping compression, core vibration (magnetostriction) or partial discharge [9].

SUMMARY

For the transformer diagnostics are many methods available. The chemical/physical analysis and the DGA are the most widely used methods for oil analysis. The PDC and FDS measurements were non-destructive methods to determine the moisture contents in the solid insulation. The FRA is a well-recognized method for the detection of mechanical displacements and deformations or mechanical damages. PD detection is another possibility for a non destructive test. New procedures are already used in addition to determine the intensity to permit the location of the PD-source. The UHF PD measurement has the advantage for on-site measurements with high sensitivity and few influences from outside disturbances. PD monitoring can provide timely and complementary information with respect to other techniques commonly in use, helping utility operators to plan maintenance actions.

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