American Journal of Electrical and Electronic Engineering, 2017, Vol. 5, No. 2, 64-68
Available online at http://pubs.sciepub.com/ajeee/5/2/5

DOI:10.12691/ajeee-5-2-5

Presenting New Idea for Circumstance Monitoring of Transformers in Power Lines

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Abstract Transformers is one of the key equipment of the power system. Power rating of the transformers varies from KVA to several hundreds of MVA. The transformer is expensive equipment of the power system. Failures of transformer usually lead to substantial profit loss to the utility, potential environmental damage, explosion and fire hazards and expensive repairing or replacement costs, thus, it is desirable that the maximum service life of transformer is required. Condition monitoring of transformer can help to increase the life of the transformer and reduce the maintenance cost. Online monitoring is the record of significant data of a transformer and analysis of data and including the history of the transformer. In this paper percent the different techniques adopted for condition monitoring of transformer.

Keywords: *power system, transformers, preventing transformer failure*

Cite This Article: Hossein Soleymani, "Presenting New Idea for Circumstance Monitoring of Transformers in Power Lines." *American Journal of Electrical and Electronic Engineering*, vol. 5, no. 2 (2017): 64-68. doi: 10.12691/ajeee-5-2-5.

1. Introduction

Power transformers are critical, key components of the power system. It plays an important role both in transmission and in the distribution system by transferring the electrical energy, from one voltage level to another, under magnetic induction reaction. Failure of transformer causes the potential environment damage, explosion, fire hazards and expensive repairing or replacement cost [1]. International experience shows that power transformers are very reliable in service and the global failure rate is less than 2 percent per year. Studies have also shown that the highest failure rates can be observed at power transformers in the upper voltage levels as depicted in Figure 1 [2]. The failure rate of transformer by some research articles has been found by the curve shown in Figure 2. It is also called as a bathtub curve. In bathtub curve represents transformer life in three stages the first stage is called infant-mortality period and it has a decreasing failure rate. Third stages, a period of wear out with an increasing failure rate [3]. Figure 3 shows the survey results for transformers with on-load tap changers. The survey results showed a 40 % failure of transformers with on-load tap changers, while 19 % were due to the windings. On the other hand 26% transformers failures due to winding without on-load tap changers, and 33 % were due to terminals [4].

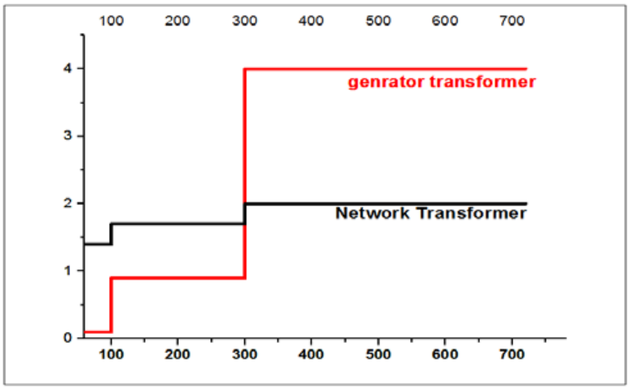

Figure 1. Breakdown rate of power transformers on voltage level

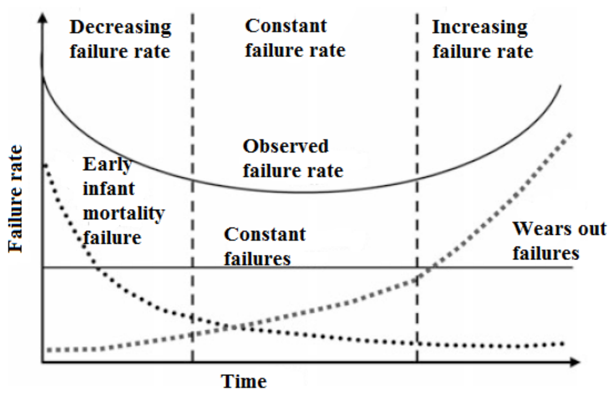

Figure 2. Typical transformer breakdown pattern

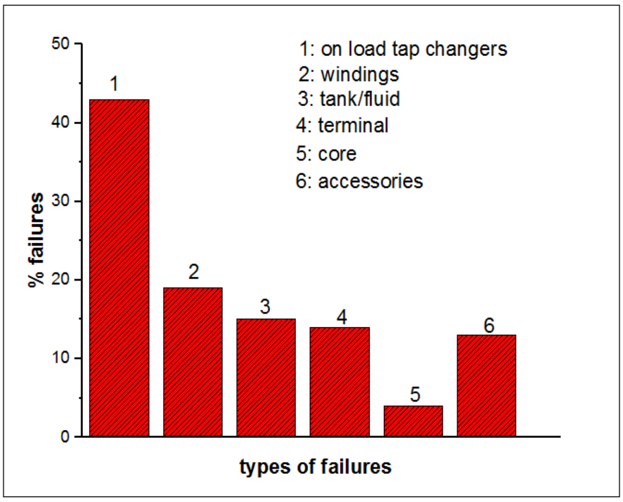

Figure 3. Survey results for failures in transformers with on-load tap changers

2. Condition Monitoring

Condition monitoring techniques are used to improve the life cycle and reduce the failure rates of transformer. Presently the load and the period of the apparatus are increasing and therefore the monitoring and diagnosis of power transformers become more and more important. Condition monitoring is techniques which are used to evaluate the present condition of the transformer and also give an idea about what will happen with transformer in upcoming time. From condition monitoring of transformer we can find out different types of fault occurring in transformer and we can take preventive action for that fault.

Online monitoring: It is the record of relevant data of a transformer. These monitored data; including the history of the transformer and by analysis of this data we get statically judge the failure rate of the transformer. The importance of the monitored transformer and the economic consequences are the basis for the quality management of power transformers together with the risk evaluation. The remaining operating life of the transformer can be estimated by recording important operating data. In order to enable a consistent utilization of the technically possible load capacity of the transformer, statements regarding the current overload capacity, for example, can be made. Online monitoring systems can help to reduce life cycle and maintenance costs of power transformers. The more accurate lifetime estimation leads to an improvement in investment strategies. The on-line monitoring of a transformer's condition or rather of the condition of its insulation involves the recording of the voltage and current as well as monitoring of the top oil temperature and, on this basis, estimation of the windings' hot spot temperature to determine the paper insulation deterioration rate.

Advantages of On-line Monitoring

1. The on-line information about the current operation condition and the calculation of current thermal stress helps to avoid unexpected outages.

2. It allows a more efficient & profitable transformer exploitation which becomes more important under the competitive conditions of the liberalized energy market.

3. Different Methods for Condition Monitoring

In this paper presents the different analytical methods adopted for condition monitoring of the power transformer are listed below.

- Dissolved Gas Analysis
- Degree of Polymerization
- Recovery Voltage Measurement
- Tangent Delta
- Insulation Resistance Test and Polarization Index
- Partial Discharge
- Sweep frequency response analysis

1. *Dissolved gas analysis scheme*:

Different patterns of gases are generated due to different forces of energy dissipated by various faults in a power transformer. Totally or partially dissolved in the insulation oil, the gases present in an oil sample make it possible to determine the nature of a fault by gas types and their concentrations. The most widely used dissolved gas extraction process is to get an oil sample through a sampling valve and inject it into an oil–gas extractor for analysis, using chromatography, mass spectrometry, infrared analytical methods, and so forth. After extraction and analysis, types of different gases and each concentration are determined, which can be compared with gas analysis records in a laboratory gathered over decades, followed by an evaluation of the impact of a fault on the serviceability of a power transformer. Once a suspicious gas presence is detected, further inspections should be carried out to identify the species and locations of faults, such as tests of no-load characteristics of winding DC resistance, insulation, partial discharge or humidity content measurements, etc. The key gas method relates gases to fault types, by these attempts to detect four types of fault.

Overheating of Oil: Decomposition products include C2H4 and CH4, with small amount of H2 and C2H6; the main gas is C2H4.

Overheating of cellulose: The principal gas is CO. Large quantities of CO2 and CO are evolved from overheated cellulose. Hydrocarbon gases, such as CH4 and C2H4, are formed if a fault involves an oil-immersed structure.

Corona: Low-energy electrical discharges produce H2 and CH4, with small quantities of C2H6 and C2H4. Comparable amounts of CO and CO2 may result from discharges in cellulose. The principal gas is H2.

Arcing: Large amounts of H2 and C2H2 are produced, with minor quantities of CH4 and C2H4. CO2 and CO may also be formed if a fault involves cellulose. The insulation oil may be carbonized. The principal gas is C2H2 [5,6,7,8].

Table 1. Faults with equivalent Key Gases

Fault	Key gases produced
Corona	H_2
Overheating of insulation	CO and CO_2
Low temperature of overheating of oil	CH_4 and C_2H_6
High temperature of overheating of oil	C_2H_4
Arcing	C_2H_2

There are three steps involved in DGA analysis. The first step is oil sampling and extraction as well as identification of the dissolved gases. The second step is to establish whether or not a fault exists in the transformer. Transformers in service always have some fault gases dissolved in oil. A fault is detected only when the levels of fault gases exceed the threshold levels. The transformers which have gas levels exceed these threshold levels are identified to have initial faults likely to cause trouble in future if allowed to go unnoticed. The third and final step is to determine the type of fault. Currently there are several methods for analysis of DGA results. It is important to note here that there is no analysis method, which can define location and the type of fault [9,10,11,12].

2. *Degree of polymerization technique:*

The number of monomer units in the polymer is known as the degree of polymerization. The measurement of the degree of polymerization is intended to determine the condition of the paper winding insulation. The sample of paper insulation of winding taken from the transformer and the average length of the cellulose chains, is determined by measuring the tensile strength of the samples. Healthy paper has an average chain length of 1000 to 1500. After an extended period of service at high temperature in an oil with a high content of water and oxygen, changes color to brown, the paper becomes hard and its degree of polymerization reduces to 150 [13]. The insulation grade paper contains about 90 % cellulose, 6–7 % hemi cellulose, and 3–4 % lignin. The natural moisture content of the paper is 4–5 % and the insulation is dried to less than 0.5 % for use in high voltage equipment. Mechanical failure of paper due to degradation is the main reason of major equipment failures [14].

Limitations:

1. The transformer tank must be opened when take the sample of the paper.

2. There is no guarantee that the sample taken from a certain position of the paper winding is representative of the complete winding.

3. *Recovery voltage dimension*:

Recovery voltage measurement is the charging and discharging process can be performed using the circuit as shown in Figure 4. The RVM technique uses the dielectric response of the insulation to evaluate the condition of the insulation with respect to moisture content and ageing. First a sample is charged for a time tc. Then, the sample is isolated from the HV source and short-circuited for a time td (tc>td). At the end of time td, the short circuit is removed and the return voltage appearing at the electrodes can be measured [15,16,17,18,19].

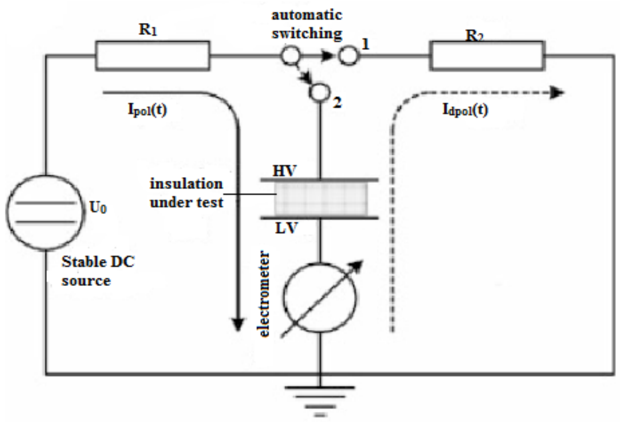

Figure 4. Two electrode method for time domain dielectric response dimensions

4. *Tangent Delta:*

The Tangent delta is a property of the electrical insulation system and its measure the electrical losses in the insulation. Low values of tangent delta are usually required as proof of the quality of the insulation. In case of increment of tangent delta value over time, are considered as a sign of decreasing of the insulation condition. The instrument has been developed for measurement of tangent delta in 10 to 12 KV range [1].

5. *Insulation Resistance Experiment and Polarization Index:*

One particular insulation resistance test result cannot accurately forecast the breakdown voltage of insulation. The results must be compared with values when the insulation was in healthy condition. Therefore, insulation resistance measurements must be taken periodically, beginning when the equipment is in healthy and new condition, and the periodical results are to be noted. When a dc voltage from a high voltage dc source is suddenly applied to insulation, the current through the insulation starts at a relatively high value, gradually decreases with time, and finally levels off to a low yet stable value. For insulation resistance measurement of transformers, the tank and the core should always be grounded. Each winding of the transformer should be short circuited at the bushing terminals. Resistance measurements are to be made between each winding, and all other windings grounded or between two windings. Windings should never be left floating for insulation resistance measurements. The principal methods used for insulation resistance measurements are: (i) Spot reading test, (ii) Time versus Resistance test, and (iii) Stepped Voltage test. Each insulation resistance test gives a different view, or window, into the condition of the insulation; the whole picture is only available when all required tests are performed.

Limitation of insulation resistance test:

(a) Unless the insulation defect is concentrated, it is impossible to specify the value of insulation resistance at which the insulation system will fail.

(b) A single insulation resistance measurement at one particular voltage does not indicate whether foreign matter is concentrated or distributed throughout the insulation system.

(c) Direct voltage measurements, such as IR and PI tests, may not detect voids present within the insulation system [20].

6. *Partial discharge dimension:*

Partial discharge is an electrical phenomenon that occurs within a transformer whenever the voltage load is enough to produce ionization, and partially bridges the insulation between conductors. In actual practice, two types of steps for measurement.

1) Regular PD measurement, which are patterns that are characteristic for a power transformer in good shape

2) Irregular PD measurement, which are patterns that represent intolerable PD sources that can relate to insulation defects after manufacturing or ageing effects during service life.

When a large population of power transformers is available for testing, a PD database can be developed for the classification of such defects in other transformers by their PD patterns. Furthermore, such a PD database also provides information about general trends in regular or irregular PD patterns as they occur during induced voltage tests. This information may contribute to a clearer insight when assessing the insulation condition of power transformers and scheduling maintenance [20,21]

7. Sweep frequency response investigation:

SFRA (sweep frequency response analysis) is tooled from which we get the condition of the core or winding movement of transformer and idea about different type of fault. SFRA requires the use of suitable equipment to produce the sinusoidal signal of variable frequency over a wide range. From this frequency take the measurement and analyze the result. For comparison of healthy condition graph of the transformer and unhealthy condition test graph of transformer, indicate the any physical change occurs and the type of fault in the transformer. For different faults and condition of winding or core frequency response is described in Table 2.

The frequency-response characteristics of the transformer windings record and measure by M5400 Sweep Frequency Response Analyzers [22-32].

Requirement of SFRA test:

- After Impulse testing of power transformer.
- Quality assurance during manufacturing.
- After short circuit testing of Power Transformer.
- Evaluate Mechanical Condition of Transformers
- Identify Core and Winding Movement.
- Due to large electromagnetic forces from fault currents.

There are several international standards and recommendations for SFRA testing of power transformers:

- Frequency Response Analysis on Winding Deformation of Power Transformers, DL/ T 911-2004, The Electric Power Industry Standard of People’s Republic of China.
- Mechanical-Condition Assessment of Transformer Windings Using Frequency Response Analysis (FRA), CIGRE report 342, 2008.
- IEEE PC57. 149™/D4 Draft Trial-Use Guide for the Application and Interpretation of Frequency Response Analysis for Oil Immersed Transformers, 2007 (Draft).
- Internal standards by transformer manufacturers.

4. Comparison of Different Techniques

After the analysis of above mention methods, the comparisons of different methods are shown in Table 3.

5. Conclusion

This paper presents the different methods adopted for condition monitoring of the power transformer. The impacts of oxidation and different ageing phenomenon have been considered. Some methods are bound to improve the measurement and corresponding interpretation of the insulation system behavior. Table 3 indicates the comparison different condition monitoring method for a power transformer.

Table 2. Frequency response for diverse faults and movement of winding

Range of frequency	Faults or deformation of winding or core
< 2kHz	Core deformation, turn shorted, open circuit
2 kHz to 20 kHz	Winding movement, clamp structure
20 kHz to 400 kHz	Moment of tap or main winding
400 kHz to 2MHz	Movement of winding lead or tap of winding, or any other connection.

Table 3. Comparisons of Diverse Methods of Conditioning Monitoring Of Power Transformers

Method	**Test**	**Monitoring availability**
Dissolved gas analysis (DGA)	Ageing of oil & paper, arcing or PD	Yes
Degree of polymerization	Ageing of insulatingPaper	No
RVM	Water content & Ageing of paper insulation	No
Tangent Delta	Dielectric losses in the insulation system	Yes
Insulation Resistance & Polarization index	Accumulation of polarize-able material	No
Partial Discharge	Deterioration of the insulation System	Yes
SFRA (sweep frequency response analysis)	Core or winding deformation and faults	Yes

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