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# Methods to Determine the Overall Health and Condition of Large Power Transformers

Godswill Ofualagba*

College of Technology, Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources, P.M.B. 1221, Effurun, Delta State, Nigeria.

* E-mail of the corresponding author: swillas@ieee.org

**Abstract**

The unsteady implementation of the conceptual model of deregulation of electric utility industry in many countries has caused significant consequences in the overall health of the general population of large power transformers [LPTs]. LPTs are now subject to adverse conditions due to advanced aging, decreases in routine testing and maintenance activities, reduction of capital for repair and replacement, increased loading and lack of technical expertise. The method presented in this paper provides a blueprint to successfully determine the overall health and condition of LPTs.

**Keywords:** Transformers, gas-in-oil, diagnostics, leakage reactance, maintenance.

## 1. Introduction

The unsteady implementation of the conceptual model of deregulation of electric utility industry in many countries has caused significant consequences in the overall health of the general population of large power transformers [LPTs]. LPTs are now subject to adverse conditions due to advanced aging, decrease in routine testing and maintenance activities, reduction of capital for repair and replacement, increased loading and lack of technical expertise. The lack of domestic manufacturing creates a number of related issues, including long distance travel, shipping, communication difficulties, and a technical expertise resource drain [1].

The owners of LPT assets are faced with often onerous decisions: replace an aging unit, often from an offshore manufacturer, or continue using the existing unit with the "hope" that it keeps on cranking out the megawatts [2]. With new units costing anywhere in a range from several hundred thousand dollars to multimillion dollars, it is imperative that this critical decision is made with the best data and information available.

Fortunately today's asset and risk managers have a varied array of tools at their disposal to help gather critical information necessary to make informed decisions. The method presented in this paper provides a blueprint to successfully determine the overall health and condition of LPTs. These methods consist of oil and electrical diagnostic testing, visual inspections, historical data trending, design review, and operations /loading/maintenance/repair review.

## 2. Method to Determine the Overall Health and Conditions of LPTs

*2.1 Oil Diagnostics*

Perhaps the simplest and least costly method of quickly assessing the general health of a LPT is to take a sample of the insulating oil. Oil sampling of a transformer is analogous to taking a blood sample from a human. Many different parameters and conditions can be accessed from an oil sample. To a trained eye, oil diagnostics provide a solid method to gain an insight into the current state of a health unit [3]. One major advantage of oil testing is that the sample can easily be taken while the unit is on-line, eliminating the need for an outage. The most commonly performed oil tests are listed below.

TABLE 1
Most Recommended Tests for In-Service Transformers

| Test Description | ASTM Method |
|---|---|
| Dielectric Breakdown | D 877 |
| Dielectric Breakdown | D 1816 |
| Neutralization Number (Acidity) | D 974 |
| Interfacial Tension | D 971 |
| Color | D 1500 |
| Water Content | D 1533B |
| Specific Gravity | D 1298 |
| Visual Examination | D 1524 |
| Power Factor | D 924 |
| Dissolved Gases in Oil | D 3612 |

Sometimes a problem is suspected and additional tests are needed to help pinpoint the issue. There are a number of additional ASTM tests available for oil diagnostics. Some additional tests are often performed in such cases as listed below.

TABLE 2
Additional Tests for In-Service Transformers

| | |
|---|---|
| Corrosive Sulfur | D 1275 |
| Furanic Compounds in Oil | D 5837 |
| Inhibitor Content | D 2668 |
| Metal-in-Oil Analysis<br>Dissolved Metals<br>Particulate metals<br>(Copper, Lead, Zinc, Iron) | |

2.2 *Dissolved Gas-in-Oil Analysis*

Dissolved gas-in-oil analysis (DGA) is the most commonly requested oil diagnostic test performed on transformer oil. All LPTs contain insulating materials that break down due to excessive thermal or electrical stress, forming gaseous by-products [3]. These by-products are indicative of the type of activity present within the transformer, such as an incipient-fault condition. The DGA can also shed light on the materials involved and the severity of the condition. DGA is a powerful tool for detecting incipient-fault conditions and for investigations after failure has occurred. Additionally, dissolved gases are detectable in low concentrations, which often allows for early intervention before failure occurs and allows for planned strategies as opposed to unplanned catastrophes. Typical gases generated from mineral oil/cellulose (paper and press board) insulated transformers include hydrogen, methane ethane, ethylene, acetylene, carbon monoxide, and carbon dioxide [3].

The composition of gases generated provides information about the type of incipient-fault condition present. For example, four general categories of fault conditions have been described and characterized by Key Gases in Table 3.

 

TABLE 3

Categories of Key Gases and General Fault Conditions

| KEY GASES | GENERAL FAULT CONDITION |
|---|---|
| Methane, ethane, ethylene, and small amounts of acetylene | Thermal condition involving the oil |
| Hydrogen, methane, and small amounts of acetylene and ethane | Partial discharge |
| Hydrogen, acetylene, and ethylene | Sustained arcing |
| Carbon monoxide and carbon dioxide | Thermal condition involving the paper |

A single sample will provide a snapshot of the transformer at a moment in the unit's history. However, the best use of oil diagnostics is to trend the recent data with other test data taken over the life of the transformer. Trending the data illustrates changes in the transformer that may go undetected in a single test. An example of an adversely trending condition in a LPT is shown in Table 4. In this example, several key gas concentrations have increased significantly, a direct result of a serious problem located within the unit.

TABLE 4

Typical Example of a Large Power Transformer Gassing History (High Temperature Incipient Fault)

| | Sampling Dates | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| GAS | 12/23/01 | 6/21/02 | 12/12/02 | 3/20/03 | 6/19/03 | 9/17/03 | 12/18/03 | 12/24/03 |
| Hydrogen | 0 | 1 | 0 | 4 | 17 | 79 | 170 | 298 |
| Oxygen | 30200 | 33700 | 30100 | 37200 | 31600 | 30700 | 30000 | 35300 |
| Nitrogen | 65300 | 67300 | 69000 | 86600 | 74400 | 65700 | 67900 | 61500 |
| Methane | 3 | 7 | 6 | 9 | 11 | 34 | 57 | 87 |
| Carbon Monoxide | 25 | 21 | 92 | 74 | 76 | 73 | 92 | 113 |
| Ethane | 0 | 0 | 2 | 5 | 11 | 36 | 44 | 69 |
| Carbon Dioxide | 2600 | 1990 | 2900 | 3100 | 2950 | 2470 | 3760 | 5830 |
| Ethylene | 1 | 3 | 20 | 34 | 95 | 160 | 211 | 334 |
| Acetylene | 0 | 0 | 0 | 1 | 3 | 5 | 23 | 33 |

*2.3. Electrical Diagnostics*

There are a number of highly effective electrical diagnostic tests available to help determine the existing health and overall condition of a LPT. A list of the most commonly performed tests is presented below followed by a brief outline of the purpose of each test.

- *Winding Power Factor*—this test measures the power loss through the insulating system caused by insulation deterioration, contamination, and mechanical deformation [7]. Abnormally high or low values of power factor, dielectric loss, capacitance, or leakage current indicate a failure of the insulation system.

- *Bushing Power Factor*—this test also measures power loss through the insulating system of the bushing. Many transformers have been saved from certain failure over the years through the detection of imminent bushing failures through use of the power-factor test.
- *Leakage Reactance*—this test is useful in detecting winding movement or core and coil displacement in LPTs.
- *Transformer Turns Ratio*—the TTR test is used primarily as an acceptance test, but can also be useful after an event to determine if the windings are short circuited [8].
- *DC Winding Resistance*—this test is used to identify a change in dc winding resistance resulting from shorted turns, defective joints, or bad contacts.
- *Core Excitation Current*— this measures the current required to excite the transformer core. High values of excitation current are generally indicative of shorted turns or core damage in the transformer.
- *Core Ground*—this test is used to identify inadvertent core grounds which cause unwanted circulating current flow, often leading to overheating situations. This test can only be performed in the field if the core ground is accessible.
- *(Sweep) Frequency Response Analysis (SFRA*)—this test is very successful in identifying core and coil anomalies such as shipping or short-circuit mechanical damage. This complex test essentially injects a signal into the coil and measures the output response at varying frequencies. Numerical analysis and fast Fourier transforms (FFTs) are used to transfer the numerical analysis into a graphical image for visual analysis. In short, the output response (Signature) of the coil is like a fingerprint. If event like a short circuit or bump causes a shift in the core and coil assembly, the graphical traces will not line up properly, indicating a problem.

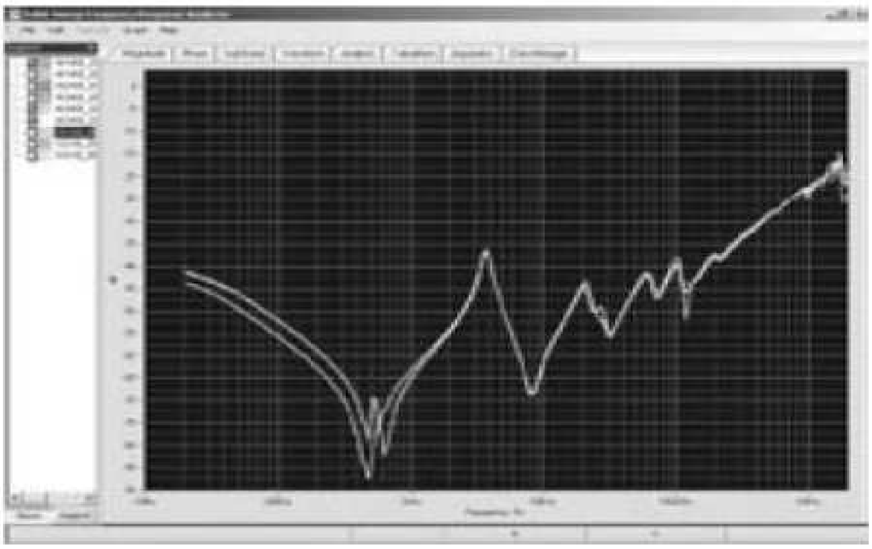

Figure 1. Three phase HV windings

*2.4. Additional Tests*

Some additional tests that can provide useful information for overall transformer health include power-factor tip-up testing, partial-discharge analysis, vibration analysis, and thermography.

*2.5. Transformer Design-Family Review*

 

All transformers have similar designs, but differences do exist between models and manufacturers. A typical assessment should include an evaluation of the unit ratings [nameplate], tank design, core/coil design, load tap-hanger[LTC]/de-energized tap-changer[DETC] design, oil thermal expansion design, bushing design, arrester design, and known common mode failure mechanisms.

### *2.6. Visual Inspection*

A thorough external visual inspection is recommended as a complement to the diagnostic testing. Items such as gaskets, pumps, fans, coolers, LTC compartments, control cabinets, piping and conduit, bushings, arresters, conductor connections, grounding, tank condition, oil containment, gauge observation, pressure relief valves, and virtually anything else attached, connected to, or mounted on the transformer should be inspected and addressed.

### *2.7. Maintenance Record Review*

The maintenance history of the unit should be reviewed to help determine its condition [6]. Issues such as oil leaks, oil processing/degassing, fan repairs/replacement, pump repairs /replacement, LTC work, or any other maintenance of the unit since it was originally placed in service should be considered in the assessment.

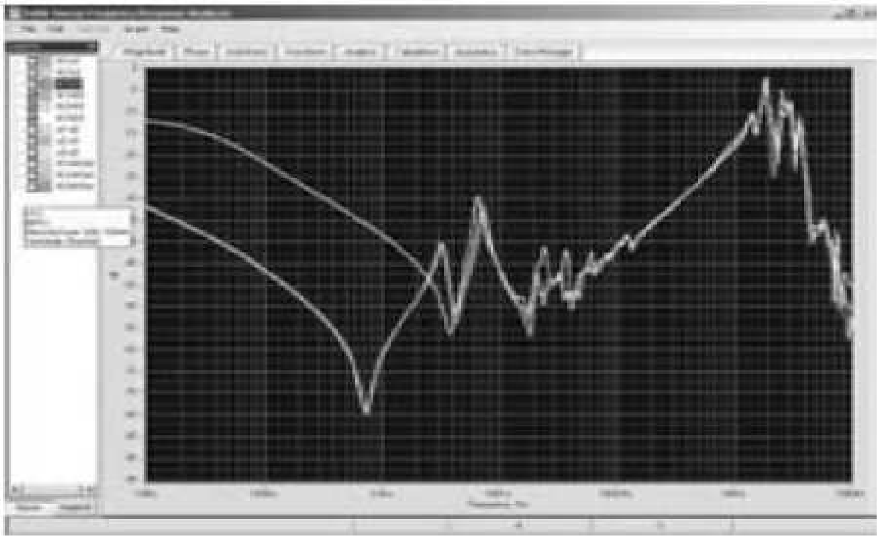

Figure 2. Three phase HV winding – shorted turns

### *2.8. Operating Record Review*

The operations and loading history should be reviewed to determine if the unit was ever exposed to over current or over excitation events, short circuits, through faults, harmonic distortions, operational limitations, grid disturbances, lightning strikes, transient phenomena or any other detrimental conditions. The loading history can be used to establish benchmark data for a thermal analysis of the unit in an effort to determine loss of life.

## 3. Conclusion

Large power transformers are very valuable assets. The life of these assets can be extended for long periods of time through the use of diagnostics as described in this paper. As a result, the life expectancy of LPTs has risen significantly over previous assumptions. There are a number of transformers in service in the United State that are 60, 70 and even 80 years old, and they are still going strong [9].

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