Transformer Oil Analysis: An Overview

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The present paper discusses the importance of transformer oil analysis (TOA) in a cost effective electrical maintenance programme. Some of the important tests in transformer oil analysis programme such as gas in oil analysis, screen tests like dielectric breakdown, power factor, interfacial tension etc, metals in oil, moisture content, PCB (Polychlorinated biphenyl) content besides other common tests including physical properties and their significance, have also been described. The description of various steps and elements of a transformer oil analysis programme and the recent developments have also been touched upon. The application of transformer oil analysis and the benefits derived in ABC Paper have also been summarized. The complete evaluation & understanding of the relation between the analysis and follow up actions in transformer oil analysis (TOA) may assure a safe & uninterrupted operation with cost effective management of transforming equipments.

INTRODUCTION

Transformer is one of the most important and strategic tools in the electrical transmission & distribution management system, the operational reliability of which in turn, depends to a large extent on the condition of the oils used in it as an insulation & heat transfer medium. Transformer oil analysis (TOA) has therefore become one of the most critical and important part of electrical maintenance programme because monitoring of transformer oils not only provides information about the condition of the oil but at the same time indicates the condition of the transformer and enables the early detection of other latent faults such as aging of insulating paper, contact acing etc. Earlier, the transformer oil analysis was limited to the monitoring of physical properties of oil but over a period of time TOA has been evolved to a complete oil analysis programme covering other tests such as dissolved gas analysis (DGA) following physical analysis with critical elements like equipment audit, monitoring and evaluation. Some petroleum based mineral oils called as transformers oils are used in the transformers as insulating, heat transfer and are quenching medium. Transformers are susceptible to problems such as overheating, partial discharges, arcing etc which in turn result in the chemical decomposition of the insulating oils producing several gases that are totally or partially dissolved in the oil. Since above defined faults i.e overheating or low energy faults can not be detected normally by electrical tests, the analysis of transformer oil has become a valuable means of detecting such malfunctions in transformers. The chemistry of insulating oil and the contaminations in the oil are the factors directly affecting the operational life of transformers. Transformer oil analysis indicates some important parameters such as dielectric breakdowr volmge, presence of conductive contaminants, colour change, presence of acids, sludge indication and many more which predict the health of a transforming equipment. Since the transformers are structurally very complicated system and hence it is difficult to determine the cause when a problem arises. Therefore, monitoring of the condition of transformer oil is particularly important for early detection of problems in order to plan the corrective action required to be taken and therefore minimizes the chances of damages & breakdowns. Keeping in the view the importance of

transformer oil analysis, some theoretical and practical aspects of transformer oil analysis have been discussed in the present paper. Some of the critical requirements of the transformer oils have been summarised in the table 1.

Significance of Transformer Oil Analysis

Table 1: Requirement of Transformer oils

Analytical Test	Requirement
Visual apperance	Change of oil color
Electrical strength of oil	> 50 kV
Water content of oil	< 20 PPM
IFT (Interfacial Tension)	> 0.015
Acidity	< 0.5 mg KOH/g
Flash point	> 125°C
Sediment (% by wt)	Nil

- Transformer oil analysis lowers the maintenance costs by replacing the practice of preventive maintenance to a more cost effective predictive maintenance.

- TOA prevents premature failure of machine components and therefore extends equipment life

- Maintenance costs and down time are reduced by eliminating unnecessary component change and premature scheduled maintenance respectively

- Better assessment of equipment performance is possible with TOA

- Lubricant costs are reduced by optimizing the drain intervals from TOA data.

EXPERIMENTAL

Transformer oil analysis was earlier limited to measuring few physical and chemical properties of oil but over a period of time, this has been evolved to a complete programme consisting of a series of steps including equipment audit, monitoring, evaluation etc. besides oil testing.

Important Steps in Transformer Oil Analysis

The sampling is the first and the most critical step in any oil analysis programme. The sampling requires care to ensure that the sample representative of the oil being sampled. The sample location should be a point where a live oil sample can be collected rather than a point where the oil is static. Documentation of the sample alongwith equipment details, operating conditions, environmental variables, type of oil, sampling procedure for meaningful oil analysis. Availability of sampling kits has now made the sampling procedure simple and reliable.

Determination of the analytical tests required for analysis of a particular oil to get the information about the oil and the condition of the equipment is the second important step in the transformer oil analysis. While making selection of analytical tests, the importance of the equipment in the plant operation, cost of repair and downtime should be given due consideration since there are a large number of tests and many of which measure the same properties. Therefore, sometimes specialized oil analytical tests may not be cost effective for the less critical equipments.

Once the data is generated from the oil analysis, the evaluation and the interpretation of the information gathered about the condition of the oil & the equipment as well are required. Evaluation of analytical data in some cases identifies a problem whereas in most of the cases, the analytical data alone is not sufficient enough to make accurate judgments about oil or equipment condition. Therefore, comparison of current sample data to previous sample and similar operations is desirable

to improve the reliability of recommendation based on analytical tests. Comparison can be made on the basis of engine types, operating environment, frequency of use, equipment type, severity of service etc.

TESTS IN OIL ANALYSIS

Various tests in transformer analysis are designed normally on the basis of two factors i.e

i) Serviceability of the oil and ii) Operating environment & equipment age.

A reasonably accurate diagnosis of a transfer oil with respect to serviceability is the outcome of collective. consideration of the following tests.

1. Acidity Test
2. Dielectric Test
3. Power Factor]
4. Interfacial Tension (IFT)

Acidity test

The Acidity test is a measure of acids formed as a result of oxidation of transformer oil under the influence of excessive temperature and oxygen, whereas the reaction is catalyzed by the: presence of small metal particles.. The increase in the acid value of oil decreases the insulating quality of the oil. Properly refined new transformer oils contain no acids. On the other hand the oxidation products of oil undergo polymerization to form sludge that precipitates out. Acidity is measured as acid number, which is equivalent to the mass of KOH in milligrams required to neutralize the acids in one gm of oil. This test is generally performed with Gerin Oil Acidity Test Kit.

Dielectric Test.

The dielectric test is performed to ascertain the dielectric strength of the transformer oil. In other words it is the measurement of the voltage at which the oil breaks down. This test serves as an indicator of the presence of contaminants such as water, dirt, moist cellulose fibres etc. Dielectric tests are conducted in accordance with AST M D 877 or ASTM D 1816 in the temperature range between 20-30 °C. The test equipments used for making dielectric tests are usually Portable Oil Dielectric Testers.

Power Factor Test

Transformer Oil power factor testing is usually carried out with the Doble type MH or M2H tester. This test is used to measure the dielectric losses and hence the dielectric heating i.e energy dissipated as heat. The comparison of the test results with the standard values reveal the quality and integrity of the insulating oil. This test is performed as an acceptance and preventive maintenance test for insulating oil..

Interfacial Tension (IFT) Test

This test is used for measuring interfacial tension of transformer oils of petroleum origin against water and gives an indication of the sludging characteristics of the transformer insulating oil. The attraction between the water molecules at the interface is influenced by the presence of polar molecules in the oil influence the attraction between water molecules at the interface. The more the polar molecules, the lower will be the IFT. Since the IFT Test measures the concentration of polar molecules in suspension and in solution in the oil ,a measurement of dissolved sludge precursors in the oil can be predicted long before any sludge is precipitated. The IFT test is performed by following the Drop-Weight Method (ASTM D 2285) in which IFT is determined by measuring the volume of a drop of water supported by oil.

Tests for Moisture Content and oxidation inhibitors are performed due to operating environment and age of the equipment.

Moisture Content

Moisture content in transformer oils affects the insulating properties of oil to a great extent and may reduce the dielectric strength of oil.. The fluctuating temperature further magnifies the effect of moisture. The moisture content also causes breakdown of cellulose insulation in the windings of some transformers as the

moisture is absorbed by the cellulose paper. This test is performed in accordance with ASTM D 1533.

Oxidation Inhibitor

The test for oxidation inhibitors is performed according to ASTM D 2668 procedure. Generally new refined transformer oils contains some amount of naturally occurring chemical compounds that retard oil oxidation. Once these compounds are exhausted, the deterioration of the oil is increased and to overcome this condition synthetic oxidation inhibitors such as 2,6-ditertiary-butyl para-cresol (DBPC) are added. Therefore this test is of significance to know the level of oxidation inhibitor present in the oil. Required DBPC content in the oil is between 0.15 percent and 0.30 percent for new equipment.

Other test used in the oil analysis are the visual appearance, color and sediment.

PCB Analysis

Polychlorinated Biphenyl (PCB) analysis of transformer oils is a part of environmental Protection Agency regulations in some countries. Transformers with oils containing more than 50 ppm PCB is considered a PCB-contaminated unit. The PCB in transformer oils are measured according to ASTM D-4059 method.

Table 2: Dissolved Gas Analysis of Transformer Oil

Gas	Normal Concentration(ppm)
Hydrogen	200
Methane	50
Ethylene	80
Ethane	35
Acetylene	6
Carbon dioxide	2000
Carbon monoxide	300

NEW DEVELOPMENTS IN TRANSFORMER OIL ANALYSIS

Earlier the transformer oil testing was limited to the above tests but now some more advanced tests Dissolved gas analysis (DGA) following the above tests has been also included.

Table 3: Various faults in Transformer due to high levels of gases

Gas	Fault
Ethylene	Severe Oil Overheating/Hot Spots
Ethane	Severe Oil Overheating/Hot Spots
Methane	Severe Oil Overheating/Hot Spots
Hydrogen	Partial Discharge, Carona
Acetylene	Arcing

Dissolved Gas Analysis in Transformer Oil

Various gases are generated in the transformers during operation. DGA is performed to determine the concentrations of certain gases in the transformer oils the relative ratios of which may be used to diagnose certain operational problems with the transformers. The type and concentration of each gas and the rate of generation can help determine operating quality of transformer as well as the type of malfunction. The normal concentration of various gases and the faults arising as a result of high levels of some major gases relative to the other gases in the transformers are summarized in Table 2 and 3 respectively.

APPLICATION OF TRANSFORMER OIL ANALYSIS IN ABC PAPER: A CASE STUDY

We at M/s ABC Paper have 11 Nos. of transformers including one power transformers with rating ranging from 1 MV A to 8 MV A.

Earlier, only dielectric strength and colour testing were being performed at regular intervals to assess the condition of the oil and the transformer as well. Since no other critical tests such as acidity, DGA etc were being

carried out. As a result of non-implementation of complete transformer oil analysis programme, the following problems were observed.

- Deposition of excessive carbon resulted in the flashing of OLTC of power transformer.

- Burning of 1.5 MV A Transformer due to excessive sludge and ageing of cellulose paper.

Keeping in view the recurring nature of above problems resulting in breakdowns ABC paper decided to start complete oil analysis. To start with, the transformer oil of all the transformers were dehydrated to remove sludge & moisture. Afterwards oil.of three transformers was completely replaced and the transformer windings were also cleaned during annual shutdown with hot pressurized oil to remove sludge and other foreign particles. Since then the transformer oil analysis is being regularly carried out and approximately Rs. 50000/- are being spent annually for implementation of oil analysis programme. Some of the advantages offered by transformer oil analysis in ABC paper are as follows:

- Smooth running of transformers without overheating

- Dielectric strength has gone above 50 KV at 2.5 mm gap in comparison to earlier 20-25 KV

- Improvement in IR values

DISCUSSION

Since the life of a transformer is dependent on the life of the insulating medium used, therefore proper analysis of the oil can help to identify the deterioration problem before it becomes too critical and severe. The breakdown voltage is indicative of the amount of contaminant in the oil. The minimum accepted dielectric strength is 30 kV and 25 kV for transformers with a high-voltage rating 287.5 kV & above and transformers with a high-voltage rating below 287.5 kV respectively. No single test determines the actual condition of the oil for example oil is not necessarily in good condition even when the dielectric strength is adequate because this tells nothing about the presence of acids and sludge: Therefore a outcome of all the test should be considered while making a recommendation

Acid number value of 0.4 is considered to be the normal service limit and sludging has been found to start when acid number exceeds 9.4. However different types of transformers would take different period of time for appearance of sludge ranging from 10 years for transformers with free air access to 67 years for transformers with nitrogen over oil.

The limit for power factor of new oil is 0.05% at 25 °C. A high power factor in used oil indicates deterioration or contamination or both. Operational hazard is expected from transformer oil with a power factor in excess of 2.0 percent and therefore requires reconditioning or replacement.

Since, the acidity test alone determines only conditions under which sludge may form but does not necessarily indicate that actual sludging conditions exist for which IFT test is required to be performed. Transformer oils with IFT values in the range of 0.015 to 0.022 N/m (15 to 22 dyn/cm) are required to be scheduled for reclaiming irrespective of acidity values. The equipment operating for 10 years or older should be tested for oxidation inhibitor concentration when the physical tests are performed. If the level of DBPC drops below 0.08%, oxidation inhibitor should be added

The integration of the results of all the tests determines the actual condition of the transformer oil and gives an indication of discarding and replacement of oil.

CONCLUSION

It may be concluded that transformer oil analysis is an important indicator of the transformer problems much before they actually arise and cause breakdown. Therefore, proper understanding, designing, training and implementation of transformer oil analysis programme in industrial operations is an essential requirement for improved plant reliability.

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