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METHODS FOR POWER TRANSFORMER FAULT ANALYSIS WITH CASE STUDIES

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ABSTRACT

In the proposed paper, we deal with three methods to undertake power transformer failure analysis. The methods are Conventional oil tests, Dissolved Gas Analysis and Furan Derivatives test. Conventional oil testing procedure includes determination of clearness, colour, viscosity, density etc. of the power transformer oil sample. Dissolved Gas Analysis is conducted to get the dissolved gas concentrations in the oil. Furan derivative analysis includes determination of Furan derivatives present in the oil that provide transformer insulation condition. The three tests were conducted on oil samples of three power transformers selected from three different substations spread across the states of Telangana and Andhra Pradesh, India. Based on the similar results of all the tests, the transformers could successfully be classified to be under 'healthy', 'moderately deteriorating' and 'extensively deteriorating' conditions.

Keywords: Power Transformers, Conventional Oil Tests, Dissolved Gas Analysis, Furan Derivatives test

I. INTRODUCTION

Power transformers performance implies power system efficiency and transfer capability. Various power transformer failures lead to minor/severe power supply interruptions, raising need of different preventive, predictive and spontaneous repair techniques to eliminate or at least minimize them. In the proposed paper, we have illustrated three methods of testing the performance of power transformers. The first one is Conventional oil sample test wherein the transformer oil sample is tested for various properties like appearance, density, acidity, viscosity and so on. The second method is Dissolved Gas Analysis, performed on oil sample to get its gas composition and characteristic faults related to gas concentration values can be analyzed. The third one is Furan derivatives test which decides the insulation paper condition through the injection of the oil sample into Furan Apparatus to give the corresponding Furan content in the oil and thus the performance can be known.

II. CONVENTIONAL OIL TESTING PROCESS

This is a commonly opted method for testing power transformer performance. Oil sample is taken from the transformer and subjected to various tests and results are analyzed to conclude the equipment condition.
The tests that are usually undertaken at the oil testing lab are briefly described below [1].

2.1 Colour and Visual

This test checks the turbidity, cloudiness, suspended particles and colour. New oil is bright and clear without visual contaminants and pale yellow in colour. Hence, while testing the oil, the colour and brightness should be checked, indicating that turbidity, cloudiness and suspended particles are within limits.

2.2 Moisture Content

This is an important test as moisture affects the dielectric properties of the oil. The fresh oil sample should not have a moisture content of more than 40ppm. Therefore, when testing the transformer oil for moisture content, the test reading should not exceed 40ppm.

2.3 Dielectric Strength (Breakdown Voltage)

A sample of used oil, on an average should not breakdown before 40kV. If the oil sample breakdowns below 40kV, then the transformer oil needs to be replaced.

2.4 Neutralization number (Acidity)

This test measures the neutralization number. When oil oxidizes in a transformer, acids and sledges are produced along with water. A severe increase in neutralization number can be detrimental to the insulation system. The neutralization number for used oil is 0.3 or less.

2.5 Power Factor

This test measures the leakage current that passes through oil. Being a sensitive indicator with regard to deterioration, it has become one of the useful tests in the industry. The greater the power factor, the more polar is the contamination in the oil. However, it can be analyzed from the dissipation factor evaluation given below.

2.6 Dielectric dissipation factor (tan delta) test

This test is also known as the loss tangent or dielectric dissipation factor measurement. Tan delta may be defined as the measurement related to the cosine of the phase angle or the sine of the loss angle. It is basically the measurement of the leakage current through the oil, which in turn is a measure of the contamination or deterioration of the oil. A normal degree of refining will result in a low value for the power factor. An oil sample should not have tan delta value more than 1.0.

2.7 Specific Resistance

At 90°C, the resistivity of transformer oil should be at least 0.1×10^{12}ohm-cm.

2.8 Density:

The preferred value of density is less than $0.89 g/cm^3$.

I.9 Flash Point:

It should not be reached before 140˚C for the oil to be of good quality.

I.10 Viscosity:

The oil's viscosity is to be maintained below $27 m^2/s$ at 27˚C.

III. DISSOLVED GAS ANALYSIS

The power transformer oil sample constitutes various gases which are significant in deciding the transformer behavior and life. These gases are generally isolated from the sample and analyzed quantitatively using Gas Chromatography process. This technique enables proper diagnosis of the transformer condition in service and can also suggest preventive measures. The main gases that are collected include: a) Hydrogen b) Methane c) Ethane d) Acetylene and e) Ethylene. Elevated concentrations of gases may signal corona, discharge, overheating, arcing or cellulose insulation pyrolysis. Also, the relative quantities of all these gases give the oil decomposition energy during a particular fault [2].

Another way for the fault diagnosis is the calculation of ratio of significant gases (Key Gas Ratios). Ratio denoting abnormal condition as per the reference standard implies the power transformer is to be taken off from service and given for rectification. Like, in one scheme, ratios used are (acetylene/ethylene), (methane/hydrogen) and (ethylene/ethane).

IV. FURAN DERIVATIVES TEST

Furan Derivatives Test is another method undertaken to monitor and thereby prevent power transformer failures. Furan (C_4H_4O) is obtained from the compound Furfural, which is also called Furan-2-carboxaldehyde, Fural, Furfuraldehyde, 2-Furaldehyde, Pyromucic aldehyde, with chemical formula OC_4H_3CHO. The furans are reported in ppm (parts per million). The amount of Furan derivatives denotes the degree of degradation (Degree of Polymerization) of the cellulose paper used in the insulation. For Furan derivatives test, the amount of furans in the oil can be computed using High Performance Liquid Chromatography (HPLC) apparatus and thus the aging of paper insulation can be analyzed.

Degree of Polymerization (DP) estimates the percentage of residual life of the solid insulation. As the degree of polymerization decreases by the age, the insulation paper gets so weak that any further stress will disrupt the paper and lead to failure. Furan derivative analysis can play a vital role in preventing unscheduled outages in electrical transmission and distribution equipment by determining the condition of the equipment factors, mainly the paper insulation.

The reference standard for the Furan derivative test is given in Table-1.

Table 1: Reference standards for furan derivatives test

Furaldehyde content (ppm)	DP value	Significance
<0.1	700-1200	Healthy
0.1-1	450-700	Moderate deterioration
1-10	250-450	Extensive deterioration
>10	<250	End of life

V. TESTS ON OIL SAMPLES

Oil samples collected from three power transformers located at three different substations were tested. The first power transformer (20MVA) located at 132kV Vijayawada substation was found to be in healthy condition. Second transformer (100MVA) located at 220 kV Chandrayanagutta substation was found to be in moderately deteriorated condition. The third transformer (15MVA) located at 132 kV Port substation was in extensively deteriorated condition. A series of tests listed earlier were carried out on the oil sample at APTransCo's Corporate Training Institute at Erragadda, Hyderabad. The test results for the power transformer under healthy condition are shown in the Tables- 2 to 10.

Power transformer oil sample test results under healthy condition:

The results of Conventional Oil tests, Dissolved Gas Analysis and Furan Derivatives test for the power transformer under healthy condition (located at 132kV Vijayawada substation) are shown in the Tables- 2, 3 and 4 respectively.

The Conventional Oil Test results for the power transformer under healthy condition are shown in the Table-2.

Table 2: Conventional Oil Test Results

Oil parameter	Reference standard (IS: 1866/2000)	Limit	Result	Remarks
Appearance	Clearness	clear & without visual contamination	clear & without visual contamination	Satisfactory
Water content (ppm)	170kV & above	20 max	NA	NA
	72.5 - 170kV	40 max	4.4	Satisfactory
	less than 72.5kV	no free water	NA	NA
Breakdown voltage (kV)	170kV & above	50 min	NA	NA
	72.5kV-170kV	40 min	60.1	Satisfactory
	less than 72.5kV	30 min	NA	NA
Total acidity(mg of KOH/g)	all voltages	0. 3 max	0.2	Satisfactory
Dielectric dissipation factor (Tan delta) at 90°C	170kV & above	0.2 max	NA	NA
	below 170kV	1.0 max	0.00385	Satisfactory
Resistivity (ohm-cm) at 90°C	all voltages	0.1E12 min	32.18E12	Satisfactory
Density (g/cm^3)	all voltages	0.89 max	0.75	Satisfactory
Flash point (˚C)	all voltages	140 min	152	Satisfactory
Viscosity (m^2/s)	all voltages	27 max	22	Satisfactory

ND – Not Determined. NA – Not Applicable.

Remarks: Results are within limits i.e., the transformer is healthy.

The reference standards and test results of Dissolved Gas Analysis are shown in the Table-3.

Table 3: Dissolved Gas Analysis Test Results

Name of the gas	Reference standard (IEC:60599/1999)			Result (ppm)			Remarks
	Upto 4 years	4 to 10 years	Above 10 years	Upto 4 years	4 to 10 years	Above 10 years	
Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	3.96	NA	Satisfactory
Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	1.52	NA	Satisfactory
Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	8.57	NA	Satisfactory
Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	0.47	NA	Satisfactory
Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	0.43	NA	Satisfactory
Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	279.43	NA	Satisfactory
Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	2188.27	NA	Satisfactory

NA – Not Applicable.

Remarks: Results are within limits i.e., the transformer is healthy.

The results of Furan Derivatives test for the above transformer is shown in the Table-4.

Table 4: Furan Derivatives Test Results

2- FURALDEHYDE (mg/kg)	0.0007

Remarks: The transformer is healthy.

Power transformer oil sample test results under moderately deteriorated condition:

The results of Conventional Oil tests, Dissolved Gas Analysis and Furan Derivatives test for the power transformer under moderately deteriorated condition (located at 220 kV Chandrayanagutta substation) are shown in the Tables- 5, 6 and 7 respectively.

The Conventional Oil test results for the power transformer under moderately deteriorated condition are shown in the Table-5.

Table 5: Conventional Oil Test Results

Oil parameter	Reference standard (IS: 1866/2000)	Limit	Result	Remarks
Appearance	Clearness	clear & without visual contamination	clear & without visual contamination	Satisfactory
Water content (ppm)	170kV & above	20 max	NA	NA
	72.5 - 170kV	40 max	11.7	Satisfactory
	less than 72.5kV	no free water	NA	NA
Breakdown voltage (kV)	170kV & above	50 min	NA	NA
	72.5kV-170kV	40 min	45	**Marginally Satisfactory**
	less than 72.5kV	30 min	NA	NA
Total acidity(mg of KOH/g)	all voltages	0. 3 max	0.2	Satisfactory
Dielectric dissipation factor (Tan delta) at 90°C	170kV & above	0.2 max	NA	NA
	below 170kV	1.0 max	0.00074	Satisfactory
Resistivity (ohm-cm) at 90°C	all voltages	0.1E12 min	260.8E12	Satisfactory
Density (g/cm^3)	all voltages	0.89 max	0.75	Satisfactory
Flash point (˚C)	all voltages	140 min	153	Satisfactory
Viscosity (m^2/s)	all voltages	27 max	22	Satisfactory

NA – Not Applicable.

Remarks: Results are marginally within limits due to the breakdown voltage being quite close to the lower limit (40kV) hence it can be concluded that the transformer is ‘moderately deteriorated’.

The reference standards and test results of Dissolved Gas Analysis are shown in the Table-6.

Table 6: Dissolved Gas Analysis Test Results

Name of the gas	Reference standard (IEC:60599/1999)			Result (ppm)			Remarks
	Upto 4 years	4 to 10 years	Above 10 years	Upto 4 years	4 to 10 years	Above 10 years	
Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	42.54	NA	Satisfactory
Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	12.62	NA	Satisfactory
Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	10.17	NA	Satisfactory
Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	2.85	NA	Satisfactory
Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	25.63	NA	Satisfactory
Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	30.58	NA	Satisfactory
Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	46.3	NA	Satisfactory

NA – Not Applicable.

Remarks: As per IEC 60599, discharge of low energy is suspected in the transformer due to the increased concentration of Acetylene.

The results of Furan Derivative test for the above transformer is shown in the Table-7.

Table 7: Furan Derivatives Test Results

2-FURALDEHYDE (mg/kg)	0.21

Remarks: The transformer has moderate deterioration.

Power transformer oil sample test results under extensively deteriorated condition:

The results of Conventional Oil tests, Dissolved Gas Analysis and Furan Derivatives test for the power transformer under extensively deteriorated condition (located at 132 kV Port substation) are shown in the Tables- 8, 9 and 10 respectively.

The Conventional Oil test results for the power transformer under extensively deteriorated condition are shown in the Table-8.

Table 8: Conventional Oil Test Results

Oil parameter	Reference standard (IS: 1866/2000)	Limit	Result	Remarks
Appearance	Clearness	clear & without visual contamination	clear & without visual contamination	Satisfactory
Water content (ppm)	170kV & above	20 max	NA	NA
	72.5 - 170kV	40 max	29.8	Satisfactory
	less than 72.5kV	no free water	NA	NA
Breakdown voltage (kV)	170kV & above	50 min	NA	NA
	72.5kV-170kV	40 min	39.2	**Unsatisfactory**
	less than 72.5kV	30 min	NA	NA
Total acidity (mg of KOH/g)	all voltages	0. 3 max	ND	NA
Dielectric dissipation factor (Tan delta) at 90°C	170kV & above	0.2 max	NA	NA
	below 170kV	1.0 max	0.00733	Satisfactory
Resistivity (ohm-cm) at 90°C	all voltages	0.1E12 min	2.91E12	Satisfactory
Density (g/cm^3)	all voltages	0.89 max	ND	NA
Flash point (˚C)	all voltages	140 min	151	Satisfactory
Viscosity (m^2/s)	all voltages	27 max	ND	NA

ND – Not Determined. NA – Not Applicable.

Remarks: The oil breaks down at 39.2kV which is less than 40kV and hence a thermal fault more than 700˚C is suspected in the transformer.

The reference standards and test results of Dissolved Gas Analysis are shown in the Table-9.

Table 9: Dissolved Gas Analysis Test Results

Name of the gas	Reference standard (IEC:60599/1999)			Result (ppm)			Remarks
	Upto 4 years	4 to 10 years	Above 10 years	Upto 4 years	4 to 10 years	Above 10 years	
Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	235.07	NA	Satisfactory
Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	49.07	NA	Satisfactory
Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	117.4	NA	Satisfactory
Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	15.7	NA	Satisfactory
Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	62.9	NA	**Unsatisfactory**
Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	245.3	NA	Satisfactory
Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	174.09	NA	Satisfactory

NA – Not Applicable.

Remarks: The transformer is suspected to have thermal fault.

The results of Furan Derivatives Test for the above transformer are shown in the Table-10.

Table 10: Furan Derivatives Test Results

2- FURALDEHYDE (mg/kg)	2.3

Remarks: The transformer is under extensive deterioration.

VI. CONCLUSION

In this paper, three different methods of determining the power transformer failure condition and failure probability have been explained with results. The Conventional Oil testing analysis, which is widely used, helps in thorough checking of the power transformer oil samples for various properties like colour, density, viscosity, resistivity etc., thereby providing the condition of the transformer. Dissolves Gas Analysis gives the concentrations of gases dissolved in the oil sample which help in determining characteristic faults associated with the individual concentrations. Furan derivative analysis helps in assessing the condition of insulation of the transformer windings.

Here, oil samples of power transformers located at three substations in India were collected and tested for possible faults. All the above mentioned tests were conducted on these oil samples. From the results of all the three methods, the transformer oil samples were found to be under three different conditions namely healthy, moderately deteriorated and extensively deteriorated conditions.

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