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Research Article

OIL TESTS AND WAVELET ANALYSIS OF FAULTS IN POWER TRANSFORMERS

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ABSTRACT
In the proposed paper, we have a comparative study of two types of power transformer failure analysis tests. The methods are Conventional oil tests and Wavelet technology-applied temperature sensor concept. Conventional oil testing procedure includes determination of gas concentrations in the transformer oil sample and diagnosing the fault from the ratio of two suitable gases. Computing method was developed for Wavelet technology application through temperature sensor to find out the fault intensity. Here, an attempt has been done to demonstrate the application of these concepts on a 132/33kV, 15MVA power transformer from Port substation in Andhra Pradesh, India, under three different conditions viz., healthy, moderately deteriorated and extensively deteriorated conditions and results obtained.

Keywords: *Power Transformers, Conventional Oil Tests, Dissolved Gas Analysis, Wavelet Technology, MATLAB*

INTRODUCTION
Power transformers become vital in deciding the power flow in large power systems. Their performance reflects power system efficiency and hence power transfer capability. However, power transformer failures in the recent past leading to power supply interruption in developing nations like India have acquired much attention. Different techniques have been designed to nullify them.
In the proposed paper, we try to illustrate two concepts to monitor a given power transformer's performance so as to get a first hand idea on its condition. The first one is oil sample test, wherein the transformer oil sample is taken for its gas composition and ratio of dissolved gases is considered to check the transformer condition. The second one includes Wavelet technology application through temperature sensor which is implemented through MATLAB code to establish the heat effect on the transformer.

MATERIALS AND METHODS
Conventional Oil Testing Procedure
This is a conventional procedure conducted at oil testing laboratories to check power transformer condition (Uzair *et al.,* 2011). Oil sample taken from the transformer is subjected to various tests and the results are analyzed before concluding the equipment fit or unfit.
The tests that are undertaken at the oil testing lab are briefly described below.
1) Colour and Visual
This test includes observing the cloudiness, suspended particles and colour.
2) Moisture Content
The fresh oil sample should not have a moisture content of more than 40ppm.
3) Dielectric Strength (Breakdown Voltage)
A sample of used oil, on an average should not breakdown before 40kV.
4) Neutralization (Acid) Number
The neutralization number for used oil is 0.3 or less.
5) Power Factor
This test measures the leakage current that passes through oil. However, it can be analyzed from the dissipation factor evaluation.

6) Dielectric Dissipation Factor (Tan Delta) Test

It is the measurement of the leakage current through the oil which, in turn, is a measure of the contamination or deterioration of the oil. The oil is non-polar and most other contaminants are polar in nature. This enables a dipole action, which this test depends upon. An oil sample should not have tan delta value more than 1.0.

7) Specific Resistance

At 90°C, the resistivity of transformer oil is supposed to be 0.1×10^{12}ohm-cm.

8) Density

The preferred value of density is less than 0.89g/cc.

9) Flash Point

The flash point is a key factor in the oil tests. It should not reach 140˚C for the oil to be of good quality.

10) Viscosity

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

Dissolved Gas Analysis

The oil sample is composed of various gases which are quite significant in deciding the transformer behavior and life. They are taken from the sample and diagnosed quantitatively using gas chromatography process. This technique enables proper diagnosis of the transformer condition in service and may also help to suggest preventive measures. The main gases collected are: Hydrogen, Methane, Ethane, Acetylene and Ethylene. The quantities of these gases help in identifying the various fault conditions. Also, the relative quantities of these gases give the oil decomposition energy during a particular fault.

Each fault has its own characteristic amount of energy. For instance, elevated concentrations of individual gases may signal corona, discharge, overheating, arcing or cellulose insulation pyrolysis (Uzair *et al.*, 2013). A comfortable way for the fault diagnosis is the calculation of ratio of suitable gases. Ratio denoting abnormal condition as per a reference standard implies the power transformer is to be taken off from service and given for rectification.

Wavelet Technology

The operation of a power transformer produces a well-defined series of vibration bursts as its signature! Due to the harmonic and non-stationary nature of the transient vibration signals, traditional frequency and time-frequency techniques are no longer effective for analysis of this type of vibration signals because the localized time domain features such as delays between bursts, the number of bursts and the strengths of bursts are sufficient to assess the condition of transformer. A wavelet transform-based technique is developed in the proposing method to characterize the transformer vibration signals. This (wavelet-based) technique gives a simplified format for displaying the essential features of the transformer vibration signatures. Application results from a selected transformer demonstrate that the features extracted in the wavelet domain can be utilized to provide reliable indications of the actual health of a transformer.

Wavelet Technology Application on Power Transformer Failure Analysis

In the proposed paper, a typical application through wavelets was used. Here, temperature sensors were provided at the power transformer location (right on the equipment body). This ensured temperature analysis at the control center through a wired communication (which can also be replaced by wireless mode like GSM, Zigbee etc). The receiver unit at the control center was connected through appropriate software (MATLAB in our case) which displayed the exact simultaneous temperature variations at the power transformer location, in the form of Wavelets.

The results from the above described methods of analyzing the power transformer failures namely Conventional oil tests, Dissolved Gas Analysis and Wavelets are described in the following Tables and Figures. For the Wavelet analysis, the waveforms were monitored for a period of 'one hour, 1 minute and six seconds' (equal to 4000 seconds!).

RESULTS AND DISCUSSION

An oil sample was collected from a 5 year old 15MVA power transformer of NGEF make located at 132kV Port substation. A series of tests listed earlier were carried out on the oil sample at APTransCo's Corporate Training Institute at Erragadda, Hyderabad, India.

For the power transformer, the Conventional oil tests and Dissolved Gas Analysis tests under different conditions are shown in the Tables - 1 to 6 while the respective Wavelet program outputs are shown in Figures 1, 2 and 3.

Power Transformer Oil Sample Test Results under Healthy Condition

The test results for the power transformer under healthy condition are shown in the Tables- 1 and 2.

The Conventional oil test results for the power transformer under healthy condition are shown in the Table 1 below.

Table 1: Conventional oil test results (healthy condition)

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Appearance	Clearness	Clear, without visual contamination	Clear, without visual contamination	Satisfactory
2.	Water content (ppm)	170kV & above	20 max	NA	NA
		72.5kV-170Kv	40 max	3.7	Satisfactory
		Below 72.5kV	No free water	NA	NA
3.	Breakdown voltage (kV)	170kV & above	50 min	NA	NA
		72.5kV-170kV	40 min	47.5	Satisfactory
		less than 72.5kV	30 min	NA	NA
4.	Acidity (mg of KOH/g)	all voltages	0. 3 max	ND	NA
5.	Dielectric dissipation factor (Tan delta)	170kV & above	0.2 max	NA	NA
		below 170kV	1.0 max	0.00381	Satisfactory
6.	Resistivity (Ω-cm)	all voltages	0.1E12 min	46.6E12	Satisfactory
7.	Density (g/cm^3)	all voltages	0.89 max	ND	NA
8.	Flash point (˚C)	all voltages	140 min	166	Satisfactory
9.	Viscosity (m^2/s)	all voltages	27 max	ND	NA

ND: Not Determined NA: Not Applicable

As per the above table, 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 2 given below.

Table 2: Dissolved gas analysis test results (healthy condition)

Sl. No.	Name of the gas	Reference standard			Result (ppm)			
		Up to 4 years	4 to 10 years	Above 10 years	Up to 4 years	4 to 10 years	Above 10 years	Remarks
1.	Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	67	NA	Satisfactory
2.	Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	14	NA	Satisfactory
3.	Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	11.3	NA	Satisfactory
4.	Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	3.2	NA	NA
5.	Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	ND	NA	NA
6.	Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	37	NA	Satisfactory
7.	Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	295	NA	Satisfactory

ND: Not Determined NA: Not Applicable

As per the above table, results are within limits i.e., the transformer is healthy.
The visible output on screen for the corresponding variations in temperature is as given in the Figure 1 below.

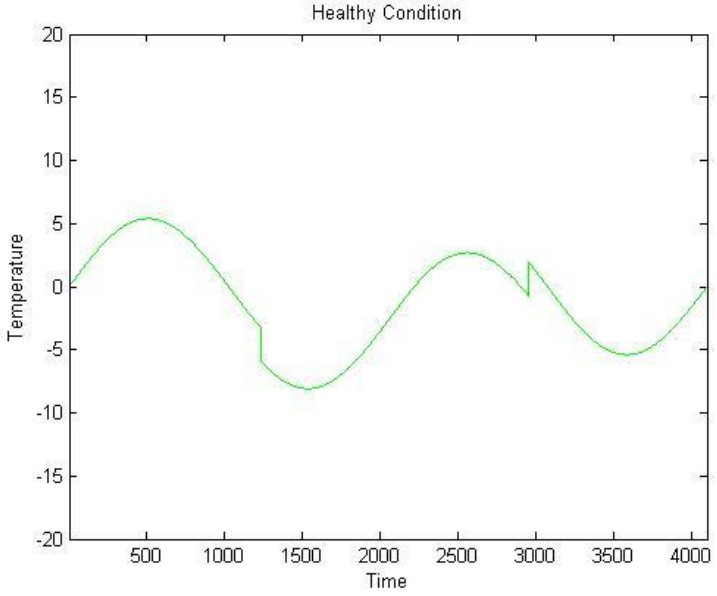

Figure 1: Wavelet Analysis Output for the transformer under healthy condition

As per the above figure, temperature-related faults are within limits i.e., the transformer is healthy.

Power Transformer Oil Sample Test Results under Moderately Deteriorated Condition

The test results for the power transformer under moderately deteriorated condition are shown in the Tables 3 and 4.

The Conventional oil test results for the power transformer under moderately deteriorated condition are shown in the Table 3 below.

Table 3: Conventional oil test results (moderately deteriorated condition)

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Appearance	Clearness	clear & without visual contamination	clear & without visual contamination	Satisfactory
2.	Water content ppm)	170kV & above	20 max	NA	NA
		72.5kV-170kV	40 max	32.6	Satisfactory
		below 72.5kV	No free water	NA	NA
3.	Breakdown voltage (kV)	170kV & above	50 min	NA	NA
		72.5kV-170kV	40 min	21.4	**Unsatisfactory**
		less than 72.5kV	30 min	NA	NA
4.	Total acidity (mg of KOH/g)	all voltages	0. 3 max	0.003	Satisfactory
5.	Dielectric dissipation factor (Tan delta) at 90°C	170kV & above	0.2 max	NA	NA
		below 170kV	1.0 max	0.0023	Satisfactory
6.	Resistivity (ohm-cm) at 90°C	all voltages	0.1E12 min	17.23E12	Satisfactory
7.	Density (g/cm^3)	all voltages	0.89 max	ND	NA
8.	Flash point (˚C)	all voltages	140 min	ND	NA
9.	Viscosity (m^2/s)	all voltages	27 max	ND	NA

ND: Not Determined NA: Not Applicable

As per the above table, the breakdown voltage is beyond limits.
The reference standards and test results of dissolved gas analysis are shown in the Table 4 given below.

Table 4: Dissolved gas analysis test results (moderately deteriorated condition)

Sl. No.	Name of the gas	Reference standard Up to 4 years	4 to 10 years	Above 10 years	Result (ppm) Up to 4 years	4 to 10 years	Above 10 years	Remarks
1.	Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	188.32	NA	Satisfactory
2.	Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	56.11	NA	Satisfactory
3.	Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	214.86	NA	Unsatisfactory
4.	Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	21.63	NA	Satisfactory
5.	Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	54.54	NA	Unsatisfactory
6.	Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	1316.48	NA	Satisfactory
7.	Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	1262.71	NA	Satisfactory

ND: Not Determined NA: Not Applicable

As per the above table, H_2 and C_2H_2 gases are very high. Please arrange for internal inspection of transformer for any mix-up of OLTC oil with main tank oil.
For the Wavelet analysis, **t**he visible waveforms on screen for the corresponding variations in temperature are shown in Figure 2 below.

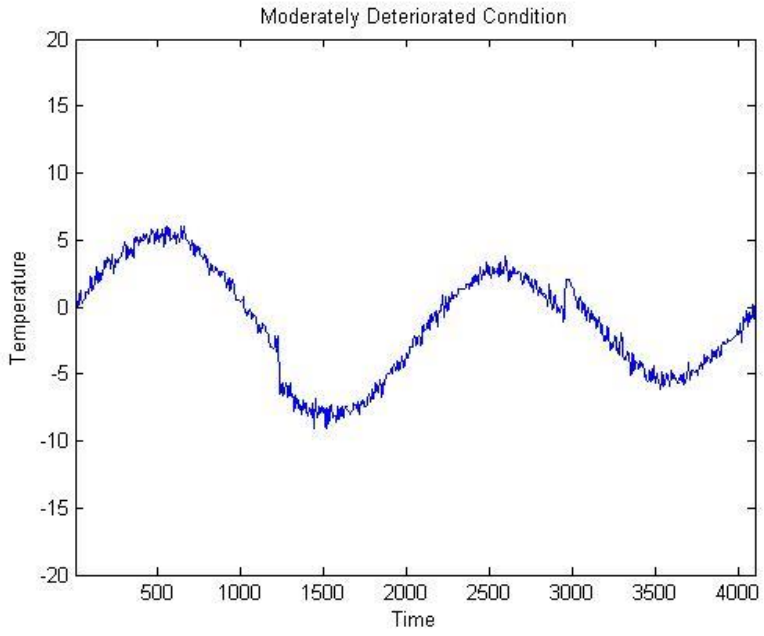

Figure 2: Wavelet Analysis Output for the transformer under moderately deteriorated condition

As per the above Figure, temperature-related faults appear to be bordering the alarming level i.e., the transformer is partially deteriorated.

Power Transformer Oil Sample Test Results under Extensively Deteriorated Condition

The test results for the power transformer under extensively deteriorated condition are shown in the Tables – 5 and 6.

The Conventional oil test results for the power transformer under extensively deteriorated condition are shown in the Table 5 below.

Table 5: Conventional oil test results (extensively deteriorated condition)

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Appearance	Clearness	clear & without visual contamination	clear & without visual contamination	Satisfactory
2.	Water content ppm)	170kV & above	20 max	NA	NA
		72.5kV-170kV	40 max	29.8	Satisfactory
		below 72.5kV	No free water	NA	NA
3.	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
4.	Total acidity (mg of KOH/g)	all voltages	0. 3 max	ND	NA
5.	Dielectric dissipation factor (Tan delta) at 90°C	170kV & above	0.2 max	ND	NA
		below 170kV	1.0 max	0.00733	Satisfactory
6.	Resistivity (ohm-cm) at 90°C	all voltages	0.1E12 min	2.91E12	Satisfactory
7.	Density (g/cm^3)	all voltages	0.89 max	ND	NA
8.	Flash point (˚C)	all voltages	140 min	151	Satisfactory
9.	Viscosity (m^2/s)	all voltages	27 max	ND	NA

ND: Not Determined NA: Not Applicable

As per the above table, the breakdown voltage is beyond limits.

The reference standards and test results of dissolved gas analysis are shown in the Table 6 given below.

Table 6: Dissolved gas analysis test results (extensively deteriorated condition)

Sl. No.	Name of the gas	Reference standard Up to 4 years	4 to 10 years	Above 10 years	Result (ppm) Up to 4 years	4 to 10 years	Above 10 years	Remarks
1.	Hydrogen (H_2)	100/ 150	200/ 300	200/ 300	NA	235.07	NA	Satisfactory
2.	Methane (CH_4)	50/ 70	100/ 150	200/ 300	NA	49.07	NA	Satisfactory
3.	Ethylene (C_2H_4)	100/ 150	150/ 200	200/ 400	NA	117.4	NA	Satisfactory
4.	Ethane (C_2H_6)	30/ 50	100/ 150	800/ 1000	NA	15.7	NA	Satisfactory
5.	Acetylene (C_2H_2)	20/ 30	30/50	100/ 150	NA	62.9	NA	**Unsatisfactory**
6.	Carbon monoxide (CO)	200/ 300	400/ 500	600/ 700	NA	245.3	NA	Satisfactory
7.	Carbon dioxide (CO_2)	3000/ 3500	4000/ 5000	9000/ 12000	NA	174.09	NA	Satisfactory

ND: Not Determined NA: Not Applicable

As per the above table, the transformer is suspected to have thermal fault due to high concentration of Acetylene.

For the Wavelet analysis, **t**he visible waveforms on screen for the corresponding variations in temperature are as given in the Figure 3 below.

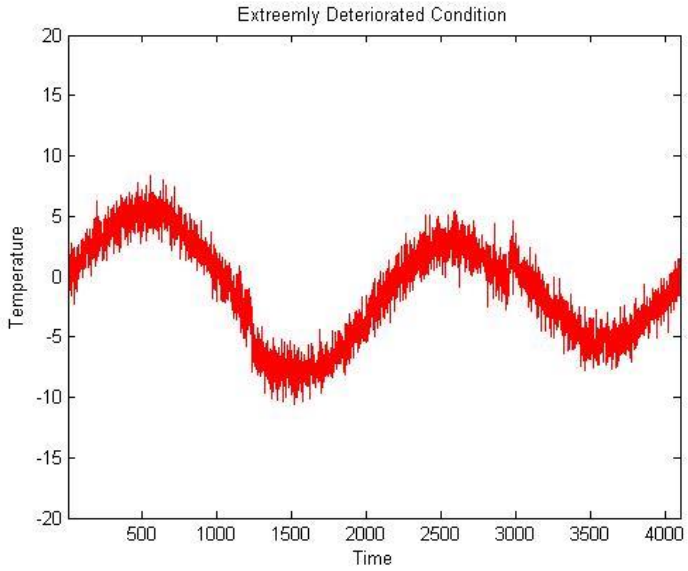

Figure 3: Wavelet Analysis Output for the transformer under extensively deteriorated condition

As per the above Figure, temperature-related faults appear to be clearly at the alarming level i.e., the transformer is severely deteriorated. The equipment may be replaced for repair/overhaul or may be scrapped!

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Conclusion

In the proposed paper, an attempt was made to explain two methods of determining the power transformer failure condition for undertaking maintenance steps as and when needed. The widely used Conventional Oil analysis checks the oil samples for various properties like colour, density, viscosity, resistivity etc. Here, we proposed Wavelet technology application through temperature sensors connected from transformer point to the control center and successfully verified through software coding. Computing method was developed for the Wavelet technology.

As a case study, transformer oil samples from 132kV Port substation (Andhra Pradesh, India) were collected and tested for analyzing the aging effect. Accordingly, the transformer's oil sample was tested for three different conditions namely healthy, moderately deteriorated and extensively deteriorated conditions, as it ages. The above mentioned tests were conducted on these oil samples. From the Oil tests and Wavelet analysis results, it was clearly seen that the transformer deterioration increases as the transformer ages.

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