DGA, WAVELET & ANN TECHNIQUES FOR FAILURE ANALYSIS OF POWER TRANSFORMERS

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ABSTRACT:

In the proposed paper, we have an evident comparative study of three types of power transformer failure analysis tests. The methods are Dissolved Gas Analysis, Wavelet technology-applied temperature sensor concept and Artificial Neural Networks approach. In Dissolved Gas Analysis, the gas concentrations are determined in the transformer oil sample for 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. Artificial Neural Networks criteria was utilized for considering the key gas concentration ratios to analyze corresponding faults. Here, an attempt has been done to demonstrate the application of these three concepts on a 132/33kV, 15MVA power transformer from Port substation in Andhra Pradesh, India, under three different conditions i.e., healthy, moderately deteriorated and extensively deteriorated conditions and results obtained.

Keywords: **Power Transformers, Dissolved Gas Analysis, Wavelet Technology, MATLAB, Artificial Neural Networks.**

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I. INTRODUCTION

Power transformers are crucial in any given power system. Power flow, power system efficiency and hence power transfer capability of large power systems are decided by these equipments. Power transformer failures lead to power supply interruptions in developing nations like India. Different techniques have been designed to nullify them.

In the proposed paper, we try to illustrate three concepts to monitor a given power transformer's performance so as to get a first hand idea on its condition and appropriate preventive/maintenance steps can be undertaken.

The first one is Dissolved Gas Analysis (DGA). Here, the transformer oil sample is taken and concentrations of key gases are analyzed to check the transformer condition.

The second one includes Wavelet technology application through temperature sensor which is implemented through MATLAB code to establish the intensity of heat effect on the transformer.

The third method has application of Artificial Neural Networks (ANN) through IEC-599 Standard ratio method for identification of the most probable fault that has occurred in the transformer.

II. 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 transformer oil 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 [1]. 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 [2].

III. WAVELET TECHNOLOGY FOR POWER TRANSFORMER FAILURE ANALYSIS

The operation of a power transformer produces a well-defined series of vibration bursts as its signature! The wavelet-based technique gives a simplified display of the essential features of these 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.

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 may also be implemented through a 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.

For the Wavelet analysis, **t**he waveforms were monitored typically for a period of a little beyond 'one hour, 1 minute and six seconds' (equal to 4000 seconds!).

IV. ARTIFICIAL NEURAL NETWORKS APPROACH FOR POWER TRANSFORMER FAILURE ANALYSIS

For the application of Artificial Neural Networks concept to the power transformer failure analysis, we checked for the various available probability computation methods and short-listed one of them.

Rogers, Dornenberg and IEC-599 are the most commonly used ratio methods. They employ the relationships between key gas contents. The key gas ppm values are used in these methods to generate the specific ratios, which represent characteristic failures in the power transformer[3].

The IEC method uses gas ratios that are combinations of key-gas ratios C_2H_2/C_2H_4, CH_4/H_2 and C_2H_4/C_2H_6.

The three gas ratios and corresponding to the suggested fault diagnosis in the power transformers as per the IEC-599 Standard [4] can be summarized as in the Table-1 below. When key-gas ratios exceed specific limits, incipient faults shown against the ratio values can be expected in the transformer.

Table-1: Gas ratios and corresponding faults in transformers as per IEC 599 [4]

Fault type	C_2H_2/C_2H_4	CH_4/H_2	C_2H_4/C_2H_6
Partial Discharge (PD)	< 0.1	< 0.1	< 0.2
Discharge under low energy (D1)	> 1	0.1 – 0.5	> 1
Discharge under high energy (D2)	0.6 - 2.5	0.1 - 1.0	> 2
Fault at low temperature (T1)	< 0.1	> 1	< 1
Fault at low to medium temperature (T2)	< 0.1	> 1	1 – 4
Fault at high temperature (T3)	< 0.1	> 1	> 4

V. OIL TESTS ON A SAMPLE

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 [2].

The results from the above described methods of analyzing the power transformer failures namely Dissolved Gas Analysis, Wavelet technology and Artificial Neural Networks concept are described in the following Tables and Figures.

For the power transformer, the Dissolved Gas Analysis tests under different conditions are shown in the Tables-2, 4 and 6 while the respective Wavelet program outputs are shown in Figures 1, 2 and 3. The results on applying Artificial Neural Networks concept are given in the Tables-3, 5 and 7.

Power Transformer Oil Sample Test Results under Healthy Condition:

Dissolved Gas Analysis results and the reference standard values 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 [4 to 10 years	Result [4 to 10 years] (ppm)	Remarks
1.	Hydrogen (H_2)	200/ 300	3.96	Satisfactory
2.	Methane (CH_4)	100/ 150	1.52	Satisfactory
3.	Ethylene (C_2H_4)	150/ 200	8.57	Satisfactory
4.	Ethane (C_2H_6)	100/ 150	0.47	Satisfactory
5.	Acetylene (C_2H_2)	30/50	0.43	Satisfactory
6.	Carbon monoxide (CO)	400/ 500	279.43	Satisfactory
7.	Carbon dioxide (CO_2)	4000/ 5000	288.27	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.

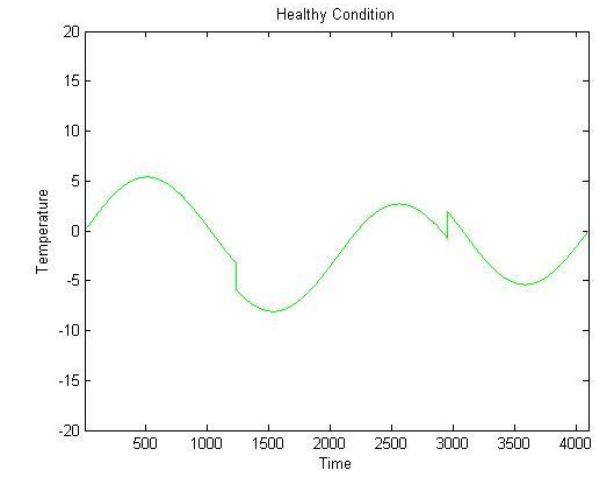

Figure1: Wavelet Analysis Output for the transformer under healthy condition

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

The Artificial Neural Network application results are as shown in the Table-3 below.

Table-3: Artificial Neural Networks approach results (Healthy condition)

Ratio of gas	Ratio value	Fault type (as per IEC-599)
C2H2/C2H4	0.05017	No fault condition!
CH4/H2	0.3838	
C2H4/C2H6	18.2340	

As per the above table, the ratio values are out of range compared to those considered for fault conditions. As per IEC- 599, the power transformer is healthy.

Power Transformer Oil Sample Test Results under Moderately Deteriorated Condition:

Dissolved Gas Analysis results for the transformer under moderately deteriorated condition, along with the reference standard values are shown in the Table-4.

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

Sl. No.	Name of the gas	Reference standard [4 to 10 years]	Result [4 to 10 years] (ppm)	Remarks
1.	Hydrogen (H_2)	200/ 300	42.54	Satisfactory
2.	Methane (CH_4)	100/ 150	12.62	Satisfactory
3.	Ethylene (C_2H_4)	150/ 200	10.17	Satisfactory
4.	Ethane (C_2H_6)	100/ 150	2.85	Satisfactory
5.	Acetylene (C_2H_2)	30/50	25.63	**Marginally Satisfactory**
6.	Carbon monoxide (CO)	400/ 500	30.58	Satisfactory
7.	Carbon dioxide (CO_2)	4000/ 5000	46.3	Satisfactory

As per the above table, H_2 and C_2H_2 gases are very high. As per IEC 60599, discharge of low energy is suspected in the transformer.

For the Wavelet analysis, **t**he visible waveforms on screen for the corresponding variations in temperature are shown in Figure 2 below.

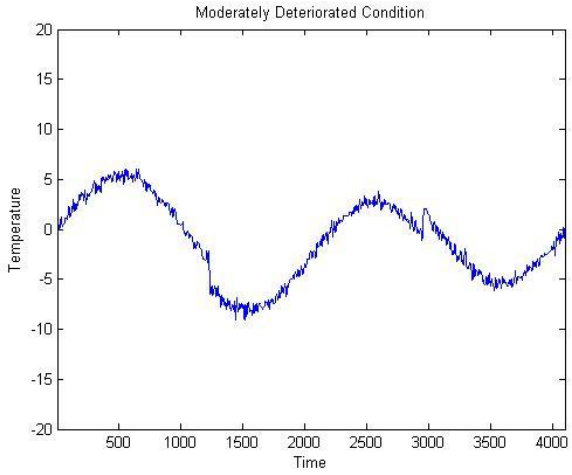

Figure2: Wavelet Analysis Output for the transformer under moderately deteriorated condition

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

The Artificial Neural Network application results are as shown in the Table-5 below.

Table-5: Artificial Neural Networks approach results (Moderately deteriorated condition)

Ratio of gas	Ratio value	Fault type
C2H2/C2H4	2.52015	Discharge under low energy (D1)
CH4/H2	0.29666	
C2H4/C2H6	3.56842	

As per the above table, the ratio values when compared with IEC- 599, indicate that the power transformer is experiencing Discharge under low energy i.e., the power transformer is moderately deteriorated.

Power Transformer Oil Sample Test Results under Extensively Deteriorated Condition:

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 [4 to 10 years	Result [4 to 10 years] (ppm)	Remarks
1.	Hydrogen (H_2)	200/ 300	235.07	Satisfactory
2.	Methane (CH_4)	100/ 150	49.07	Satisfactory
3.	Ethylene (C_2H_4)	150/ 200	117.4	Satisfactory
4.	Ethane (C_2H_6)	100/ 150	15.7	Satisfactory
5.	Acetylene (C_2H_2)	30/50	62.9	**Unsatisfactory**
6.	Carbon monoxide (CO)	400/ 500	245.3	Satisfactory
7.	Carbon dioxide (CO_2)	4000/ 5000	174.09	Satisfactory

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.

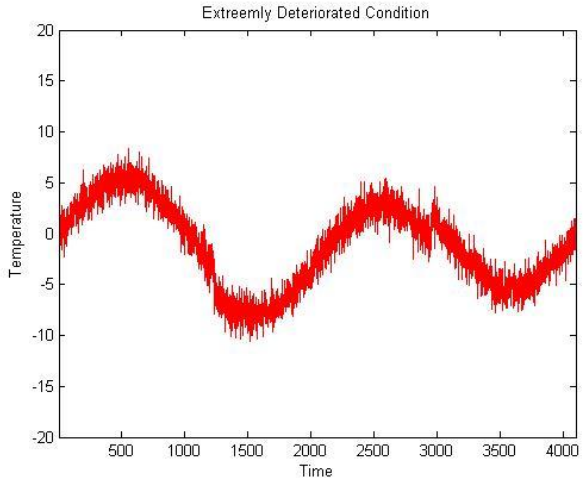

Figure3: Wavelet Analysis Output for the transformer under extensively deteriorated condition

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!

The Artificial Neural Network application results are as shown in the Table-7 below.

Table-7: Artificial Neural Networks approach results (Extensively deteriorated condition)

Ratio of gas	Ratio value	Fault type
C2H2/C2H4	0.53577	Fault at high temperature (T3) i.e., Thermal fault
CH4/H2	0.208746	
C2H4/C2H6	7.4777	

As per the above table, the ratio values when compared with with IEC- 599, indicate that the power transformer is extensively deteriorated.

VI. CONCLUSION

In the proposed paper, an attempt was made to explain three methods of determining the power transformer failure condition for undertaking maintenance steps. The first one, Dissolved Gas Analysis, checks the oil samples for gas concentrations in it, indicating characteristic faults in the transformer. Here, we proposed Wavelet technology application through temperature sensors

connected from transformer point to the control center and successfully verified through software coding. Artificial Neural Networks concept was used to establish the expected faults in a power transformer.

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 Dissolved Gas Analysis, Wavelet analysis and Artificial Neural Networks application results, it was evident that the power transformer was deteriorating with time.

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