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FAILURE ANALYSIS OF POWER TRANSFORMERS BY DGA, OIL TESTS AND MARKOV APPROACH

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Abstract: **In the proposed paper, we deal with three methods to undertake power transformer failure analysis. The methods are Dissolved Gas Analysis, Conventional Oil Tests and Markov model approach. Dissolved Gas Analysis is conducted to get the dissolved gas concentrations in the oil. Conventional Oil Tests include determination of various properties of the oil. Markov Model approach has been illustrated in the proposed paper. The three methods were implemented 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 into three different conditions.**

Keywords: **Power Transformers, Conventional Oil Tests, Dissolved Gas Analysis, Hidden Markov Models.**

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 Dissolved Gas Analysis, performed on oil sample to get its gas composition and characteristic faults related to gas concentration values can be analyzed. The second one is Conventional Oil Tests that decide failure probability percentage of the power transformer. The three methods were implemented 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 into three different conditions.

II. DISSOLVED GAS ANALYSIS

The power transformer oil sample constitutes various gases which are significant in deciding the transformer behavior and life. The main gases that are collected include: a) Hydrogen b) Methane c) Ethane d) Acetylene and e) Ethylene. 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. 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 [1].

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 given for rectification. Like, in one scheme, ratios used are (acetylene/ethylene), (methane/hydrogen) and (ethylene/ethane).

III. CONVENTIONAL OIL TESTS

This is a conventional procedure conducted at oil testing laboratories to check power transformer condition [2]. 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× 1012ohm-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 27m2/s at 27˚C.

IV. HIDDEN MARKOV MODEL APPROACH

Markov Model is the one wherein the state is directly visible to the user and the state transition probabilities are the only parameters. However, a 'Hidden Markov Model' has state not directly visible i.e., the state is 'hidden' and output, which is dependent on the state, is visible. The state sequence through which the model passes is hidden and not the parameters of the model. Even when the parameters are exactly known, the model is still 'hidden' [1] [2].

The Fault Classification:

Although the method based on the dissolved gases analysis has some characteristics which indicate that identification method and is simple with fault classification result being explicitly specific, yet the classification and boundary of this method is over-absolute in practice. There still exist some mistaken phenomena which include:

(1) Many compound fault problems aren‘t still solved carefully in actual such as electric discharge merge overheat etc, and

(2) There exit some overlap distribute phenomena in the ratio boundary adjacent.

Therefore, there are still many misjudges, lacking judges or non-judging cases during the actual fault diagnosis. The occurrence probability of these cases is relatively small and will be not considered when large quantity power transformers are counted and analyzed. But, these cases shouldn‘t be ignored and the DGA method should be improved for each power transformer. Each ratio in the new IEC three ratios method has different space interval. Based on the data statistics for large quantity power transformers with fault and referenced to some relative classification methods, the fault pattern for power transformer is classified as seven types. They are normal, overheat under moderate or low temperature (not more than 700˚C), overheat under high temperature (more than 700˚C), discharge under low-energy, discharge under high-energy, discharge under low-energy merge overheat, discharge under high-energy merge overheat.

Characteristic Variables Determination:

The purpose that some useful information obtained from the DGA data is to proceed for the pattern identification. The gas ratio selection and the characteristic dimensional will determine the fault classification correctness to some degree. There are several useful characteristic gases to judge oil filled transformer inner faults: hydrogen, methane, ethane, ethane, acetylene, ethylene, carbon monoxide and carbon dioxide. However, because of the easy presence of carbon dioxide in the air and insensitiveness to the faults, carbon dioxide shouldn‘t be considered as a fault characteristic gas. When some latent faults on power transformer occur, the carbon monoxide gas density may be

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much more than that of other characteristic gases. It will have an effect on the output probability computation in HMM model building and pattern classification for the other characteristic gases produced. In order to simplify problems and combine the actual condition for HMM model building and fault classification, there are five gases selected. They are hydrogen, methane, ethane, ethylene and acetylene. Carbon monoxide is considered as one of the characteristic gases to measure the power transformer running state. Now, the characteristic gas vector quantity composed of Dissolved Gas Analysis(DGA) data can be shown as:

$$X = [H_2, CH_4, C_2H_6, C_2H_4, C_2H_2]$$

HMM Training and Fault Diagnosis Model Library Establishing: HMM is trained as a representative of the power transformer normal working condition to the power transformer fault diagnosis. For all possible occurrence fault patterns, the HMMs are trained and a fault diagnosis model library is prepared. In order to judge a characteristic gas attribute to which types of fault, the signal must be preconditioned, and then compute each model's output probability in fault model library, compare all probabilities, take out the maximal output probability model and make the final fault decision. The output probability computation can be realized by the forward-backward algorithm or Viterbi algorithm. Once the HMM initial model is established, the training of HMM can be obtained by the iterative computation using the recurrence-thought Baum-Welch algorithm. The logarithmic value of maximum likelihood estimated value will be increasing till the convergence error and end since the iterations increase in HMM. Training of HMM has rapidly leaning performance and would have reached the convergence error in several steps domain in general. The important outputs after model training are state transition probability matrix and observable value probability matrix. The five fault patterns that include normal, overheat under moderate or low temperature, overheat under high temperature, discharge under low-energy, discharge under high-energy are modeled respectively by HMM. Each model training iterative curve shows that HMM has strong learning ability. HMM Fault Diagnosis: This is used for classification. Different fault characteristic patterns should build HMM, and the characteristic gas observable value can be used to quantify the sequence at fault classification. The probability _P(O|λ)' is calculated and reasoned by the forward-backward algorithm or Viterbi algorithm, then the probability output result is compared and the decision is made by the maximal output. For example, if _λi' output probability is at the most, the fault pattern _ωi' will be judged. The quantification sequence for the characteristic gases observable vector quantity given by:

$$X = [H_2, CH_4, C_2H_6, C_2H_4, C_2H_2]$$

This will be used as the input vector quantity, and the fault is classified by the built-in HMM. There are two types of outputs for HMM classification. The first one is HMM export logarithmic likelihood probability computation result. Another is the fault possibility corresponding to each of fault modes.

The HMM method is thus used to get the fault diagnosis i.e., fault probability of the transformer with the help of MATLAB coding on a computer.

Flowchart for Hidden Markov Models Program: A flowchart for the fault diagnosis using HMM is shown in the Figure-1 below.

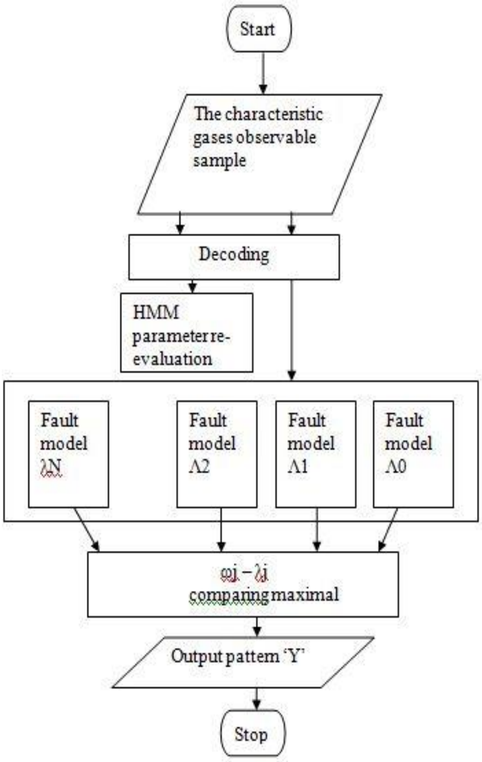

Fig. 1: Flowchart for HMM program

Description of the flowchart:

The characteristic gases from the power transformer oil sample are taken.
Decoding is done for them so as to be understandable to the system.
Fault models from the fault model library are compared with the input gas concentrations.

The fault model which is most similar i.e., having the maximal output with respect to the input, is considered and is given as output.

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 (Andhra Pradesh) was found to be in healthy condition. Second transformer (100MVA) located at 220 kV Chandrayanagutta substation (Hyderabad, Telangana) was found to be in moderately deteriorated condition. The third transformer (15MVA) located at 132 kV Port substation (Andhra Pradesh) was in extensively deteriorated condition. The test results for the power transformer under healthy condition are shown in the Tables- 1 to 6. The Markov Analysis results are shown in Figures- 2, 3 and 4.

Power transformer oil sample test results under healthy condition:

The results of Dissolved Gas Analysis, Conventional Oil tests and Markov Analysis for the power transformer under healthy condition (located at 132kV Vijayawada substation) are shown in the Tables- 1 and 2 and Fig-2 respectively.

The reference standards and test results of Dissolved Gas Analysis are shown in the Table-1.

Table-1: Dissolved Gas Analysis Results

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	2188.27	Satisfactory

NA – Not Applicable

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

The results of Conventional Oil tests for the above transformer are shown in the Table-2.

Table-2 Conventional Oil Test Results

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Visuality	Clearness	Clear	Clear	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

The output on screen for the Markov Model Analysis is as given in the Figure-2 below.

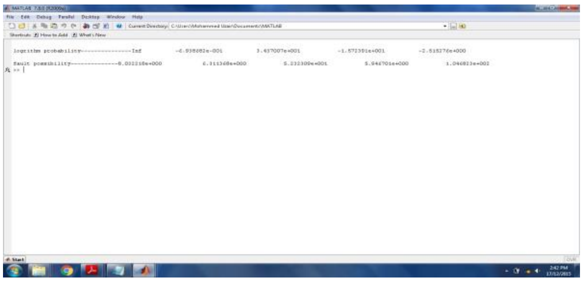

Fig. 2: Markov Analysis Output for the transformer under healthy condition

As per the above figure, the fault probability percentage under high temperature is **52.32%**.

Power transformer oil sample test results under moderately deteriorated condition:

The results of Dissolved Gas Analysis, Furan Derivatives test and Wavelet Analysis for the power transformer under moderately deteriorated condition (located at 220 kV Chandrayanagutta substation) are shown in the Tables- 3 and 4 and Fig-3 respectively.

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

Table-3: Dissolved Gas Analysis Results

Sl. No.	Name of the gas	Reference standard [4 to 10 years]	Result [4 to 10 years] (ppm)	Remarks
1.	Hydrogen (H2)	200/ 300	42.54	Satisfactory
2.	Methane (CH4)	100/ 150	12.62	Satisfactory
3.	Ethylene (C2H4)	150/ 200	10.17	Satisfactory
4.	Ethane (C2H6)	100/ 150	2.85	Satisfactory
5.	Acetylene (C2H2)	30/50	25.63	Marginally Satisfactory
6.	Carbon monoxide (CO)	400/ 500	30.58	Satisfactory
7.	Carbon dioxide (CO2)	4000/ 5000	46.3	Satisfactory

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

The results of Conventional Oil tests for the above transformer are shown in the Table-4.

Table-4: Conventional Oil Test Results

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Visuality	Clearness	Clear	Clear	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	Un-Satisfactory
		less than 72.5kV	30 min	NA	NA
4.	Acidity (mg of KOH/g)	all voltages	0.3 max	0.003	Satisfactory
5.	Dielectric dissipation factor (Tan delta)	170kV & above	0.2 max	NA	NA
		below 170kV	1.0 max	0.0023	Satisfactory
6.	Resistivity (Ω-cm)	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	166	Satisfactory
9.	Viscosity (m^2/s)	all voltages	27 max	ND	NA

The output on screen for the Markov Model Analysis is as given in the Figure-3 below.

Fig. 3: Markov Analysis Output for the transformer under moderately deteriorated condition

As per the above figure, the fault probability percentage under high temperature is **62.059%**.
Power transformer oil sample test results under extensively deteriorated condition:

The results of Dissolved Gas Analysis, Furan Derivatives test and Wavelet Analysis for the power transformer under extensively deteriorated condition (located at 132 kV Port substation) are shown in the Tables- 5 and 6 and Fig-4 respectively.

The reference standards and test results of Dissolved Gas Analysis are shown in the Table-5.

Table-5: Dissolved Gas Analysis Results

Sl. No.	Name of the gas	Reference standard [4 to 10 years]	Result [4 to 10 years] (ppm)	Remarks
1.	Hydrogen (H2)	200/ 300	235.07	Satisfactory
2.	Methane (CH4)	100/ 150	49.07	Satisfactory
3.	Ethylene (C2H4)	150/ 200	117.4	Satisfactory
4.	Ethane (C2H6)	100/ 150	15.7	Satisfactory
5.	Acetylene (C2H2)	30/50	62.9	Un-satisfactory
6.	Carbon monoxide (CO)	400/ 500	245.3	Satisfactory
7.	Carbon dioxide (CO2)	4000/ 5000	174.09	Satisfactory

Remarks: The transformer is suspected to have thermal fault.

The results of Conventional Oil tests for the above transformer are shown in the Table-6.

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Table-6: Conventional Oil Test Results

Sl. No.	Oil parameter	Reference standard	Limit	Result	Remarks
1.	Visuality	Clearness	Clear	Clear	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	Un-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	ND	NA
		below 170kV	1.0 max	0.00733	Satisfactory
6.	Resistivity (Ω-cm)	all voltages	0.1E12 min	2.91E12	Satisfactory
7.	Density (g/cm^3)	all voltages	ND	NA	NA
8.	Flash point (˚C)	all voltages	151	Satisfactory	Satisfactory
9.	Viscosity (m^2/s)	all voltages	ND	NA	NA

The output on screen for the Markov Model Analysis is as given in the Figure-4 below.

Fig. 4: Markov Analysis Output for the transformer under extensively deteriorated condition

As per the above figure, the fault probability percentage under high temperature is **72.669%**. results of Furan Derivatives Test for the above transformer are shown in the Table-7.

VI. CONCLUSION

In this paper, three different methods of determining the power transformer failure condition and failure probability have been explained with results. The Dissolves Gas Analysis gives the concentrations of gases dissolved in the oil sample which help in determining characteristic faults associated with the individual concentrations.

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.

VII. REFERENCES

[1] Uzair M.A.R., and Dr. Basavaraja B., 2015, "DGA, HMM & Wavelet Concepts for Power Transformer Failure Analysis", International Journal of Applied Engineering and Technology (CiBTech), 5(4).

[2] Uzair M.A.R., and Dr. Basavaraja B., 2015, "Case Studies of Power Transformer Fault Analysis", International Journal of Science, Engineering & Technology Research (IJSETR), 4(12).