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Decision Tree Based UV/VIS Response To Access the age of Transformer Oil

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Abstract - Diagnostics and proper monitoring of power transformer plays a key role in the life expectancy of proper transformer. Mineral oil in transformer is the inseparable component of the dielectric insulation system. Information about the health of the power transformer that can be use to plan cost, maintenance, renovation and operational criteria can be accurately interpreted using UV-Spectrophotometer. As UV scan can only show the pictorial information of the age of the oil hence it is not advantageous in all aspects. In the present paper a decision tree method to determine the age of the transformer oil is introduced. The decision tree uses the UV/VIS spectroscopy absorbance values of the transformer oil which are in service at several locations. The decision tree method is designed so that the results of transformer oil can be examined quickly and automatically. The results obtained are compared with the UV/VIS spectroscopy for testing the accuracy of the decision tree and found that it is 100% accurate.

Index Terms— Decision tree, Transformer oil, Ultraviolet spectrophotometer.

I. INTRODUCTION

Power transformer is most significant and extremely important element in the utility industry. Transformers are key-stone in transmission and distribution system. The failure of one transformer may cause significant effect for electrical utilities. In electrical energy market due to competition require enhanced system reliability due to periodic diagnostic to avoid sudden failure and losses due to outage duration. Failure coming without warning which is responsible for large economic losses and large outage. In the absence of critical components monitoring and diagnostics, the failure risk always remain high. Consequently, an occurrence of fault in the transformer disturbs the power system operation within a range leading to non-uniform power supply. The fault occurrence cannot be avoided at all times but complete monitoring of the transformer condition is useful in taking precautions and forecasting. The monitoring can be done on any part of a transformer and oil which forms coolant part of transformer behaves exactly with the abnormal operation transformer. The aging of the oil is also an important aspect which maintains the steady operation of transformer. Various tests on transformer oil can be done to ensure exact operation. Nowadays new monitoring and diagnostic technologies are introduced for the purpose of condition assessment of transformers. The various test which can be done on transformers oil are viz Dissolved gas analysis(DGA), Sweep frequency response analysis (FRA), Tan Delta tests, Breakdown voltage (BDV), Interfacial tension (IFT), and Ultraviolet spectrophotometer (UV/VIS). The DGA test is done so that the level of the gases present in the oil can be determined. It is a very efficient way in monitoring the oil health and the process is a bit lengthy. SFRA is an OFF line testing method and it can be carried out for any voltage rating of Power Transformer, Generator Transformer and Distribution Transformer. The measurement of SFRA can be a part of regular transformer maintenance. The SFR Analyzer identifies the core movement, winding deformation and displacement, faulty core ground, partial winding collapse, hoop buckling, broken or loosened clamping structures, shorted turns and open winding abnormalities in the transformer before they lead to failure. The Technique of SFRA is a major advance in transformer condition monitoring analysis.

Break down voltage (BDV) method measures the stability of the oil to with stand electric stress. The measurement of break down voltage, indicate the presence of the contaminants such as water or conducting particles. Tan-Delta test Tan Delta, also called Loss Angle or Dissipation Factor testing, is a diagnostic method of dielectrics present in a transformer to determine the quality of the insulation. This is done to predict the remaining life expectancy and in order to prioritize cable replacement and/or injection. It is also useful for determining what other tests may be worthwhile. Interfacial Tension (IFT) The interfacial tension between oil and water provides a means of detecting soluble polar contaminants and products of deterioration.

Besides these methods UV Spectrophotometry is a method which provides a platform for visual identification of the age of the oil. Though the method is not supreme compared to the other methods but it got some advantages in terms of accuracy and visualization. UV/VI Spectrophotometer is a technique used for the ageing analysis of the transformer oil with respect to the contamination present in it. The oil gets contaminated mainly due to ageing, acid, sludge, moisture and dust particles due to which the oils chemical and physical properties changes. The Ultraviolet spectrophotometer is an OFF line test, this test method characterize by spectrophotometer the relative level of dissolve decay products in mineral insulating oil of petroleum origin.

Visual identification will be efficient only if a person conversant with the technical aspects. Hence the present paper concentrates on using expert system based on UV/VI Spectrophotometer response for determining the health assessment of the transformer oil. A decision tree is used to automatically identify the age of the oil. As the test method is applicable to compare the extent of dissolve decay products for oil in service, seven samples of transformer oil from different substations are collected and analyzed using UV/VI Spectrophotometer. These oil samples are scanned using UV scan and the absorbance values obtained are used to feed the decision tree for identification.

II. UV SPECTROPHOTOMETER

UV Spectrophotometer is an accurate method to analyze the impurities and determining age based on it. The ultraviolet spectroscopy refers to absorption spectroscopy in ultraviolet visible spectral region. This test is generally carried out on transformer oil by using light absorbing properties of the sample. The absorption in visible range directly affects the perceived color of the chemical involved. This test method is applicable to compare the extent of dissolve decay products for oil in service. A spectrophotometer measures the transmission, absorption or reflection of the light spectrum for the given wavelength.

The Beer's law provides a linear relationship between absorbance and concentration of an absorber of electromagnetic radiation such as:

$$A = a_\lambda \times b \times c \qquad (1)$$

where A is the measured absorbance, λ is a wavelength dependent on absorption coefficient, b is the path length, and c is the sample concentration, also:

$$A = \varepsilon_\lambda \times b \times c \qquad (2)$$

where is the wavelength dependent on the molar absorption. The λ subscript is often dropped with the understanding that a value for ε is for a specific wavelength. If multiple species that absorb light at a given wavelength are present in a sample, the total absorbance at that wavelength is the sum due to all substances:

$$A = (\varepsilon_1 \times b \times c_1) + (\varepsilon_2 \times b \times c_2) + \ldots\ldots\ldots\ldots \qquad (3)$$

The subscripts 1,2 refer to the molar absorption and concentration of different absorbing impurities present in the sample. Experimental measurements are made in terms of transmittance T which is defined as:

$$T = P/P_o$$

where P is the power of light after it passes through the sample and P_o is the initial power of the light. The relation between A and T are defined as:

$$A = -\log(T) = -\log P/P_o \qquad (5)$$

UV/VIS has been in general use for last 35 years and over this period has become most important analytic instrument. The UV spectrophotometer provides reasonable information on the power transformer to plan relocation and operational criteria.

III. EXPERIMENTAL SETUP AND PROCEDURE

An experiment is carried out to obtain the absorbance values of various samples of transformer oil. The experiment has been done according to ASTM D-6802 [REF]. Initially the UV Spectrophotometer is zeroed with spectral grade heptane. During this process heptane is placed in 10mm path length glass cuvette, which is installed in UV/VI spectrophotometer. The cuvette with Heptane is then placed in the reference position in the instrument. The second cuvette is filled with the transformer mineral oil sample to be tested. The cuvette holder and cuvette containing the Heptane and transformer oil is pictorially represented in Fig.1

Fig. 1 : Cuvette holder and cuvette containing oil sample

The cuvette with oil is placed so that the absorbance curve of the mineral oil can be determined. The absorbance curve is obtain from the instrument which scans in the range of 360-600nm. The graph is obtained between wavelength versus absorbance of the given oil samples. The relationship exists between the absorbance curve and the total amount of dissolve decay products in mineral insulating oil. The absorbance curve to the shorter wavelength indicates that the oil is new. The shift of the absorbance curve to shorter wavelength after reclaiming used or stored oil indicates the selective removal of dissolved decay products whereas, the shift under the longer wavelength indicates an increases content of the dissolved decay products in the oil. Thus it indicates the condition of transformer oil. The complete setup of the procedure discussed above is shown in Fig. 2.

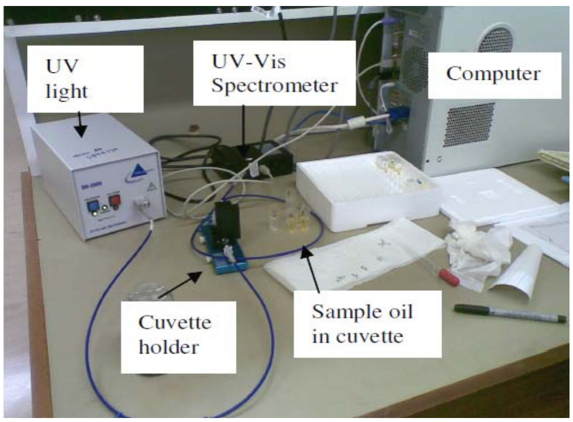


Fig. 2 An assembly of uv/vis with oil samples and PC interface

The assembly shows the complete setup of UV Spectrophotometer, the function of each equipment is as explained above. The graphs obtained from the UV Spectrophotometer for different oil sample are shown from Figures 3 to 6.

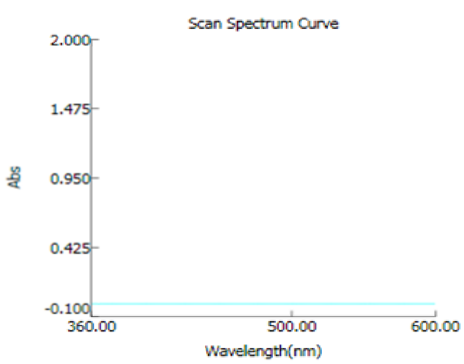


Fig. 3 Show the base line (heptane)

Fig. 3 shows the UV spectrophotometer plot obtained from the Heptane sample which forms the base line. This is done to fulfill the zero condition of the instrument by adjusting it to read zero absorbance. The value obtained is constant and is equal to -0.082. The wavelength which the instrument is scan is in range of 360-600nm.

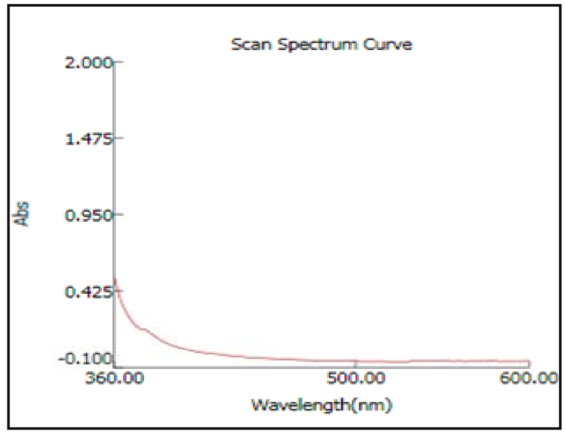


Fig. 4 shows the UV Spectrophotometer plot obtained for fresh oil sample. For obtaining this graph the heptane-filled cuvette is moved to the reference position as mentioned previously. Now the second glass cuvette is filled with the transformer oil sample and placed into sample holder. Then the UV scan is started to obtain the plot. As it is seen from Fig. 4 that there is a shift of the absorbance curve obtained from UV scan. It is seen that absorbance value decreases from wavelength 360-600nm. Such behavior of the change in the shift of the absorbance curve indicates that the oil is fresh and indicates that there is a removal of dissolved decay products.

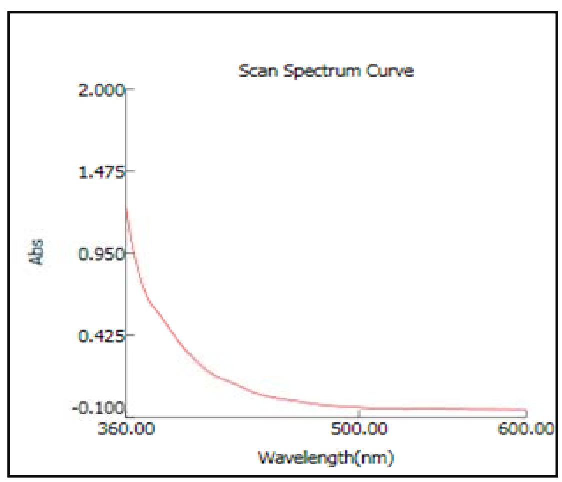


Fig. 5 Medium age transformer oil

The UV Spectrophotometer plot obtained for medium aged transformer oil is shown in Fig. 5. The initial value of the absorbance has increased compared to the value in Fig. 4. The behavior of the absorbance versus wavelength is same but there is deviation in the curve, which indicates the presence of the dissolve decay products and impurities in the oil which due to aging of the oil.

The UV Spectrophotometer plot obtained for highly aged transformer oil is shown in fig. 6. Interestingly the value of the absorbance has increased in this case too as compared to Fig. 5. The absorbance curve which is obtained from this graph after UV scan indicates that there is increased content of dissolved decay products in transformer oil. An overall observation of all the plots obtained from the UV spectrophotometer shows that the curve shifts from the lower to higher side if there is a presence of impurities in the sample oil. However, such information will be helpful to the persons who are well conversant with technical background.

The efficiency of the method will be high if it is possible to automatically identify the age of the oil. It will be more useful to the technicians if the information about the age of the oil is identified automatically. Hence, the decisive output regarding age of the oil in terms of characteristics like new oil, medium aged oil and highly aged oil is more useful. For designing an automatic system the parameters obtained from the UV Spectrophotometer scan can be used. A decision tree is proposed in the paper. The age of the oil is classified as new, medium and highly aged oil. If the oil is not in commission or of 1 year age it categorized as new oil. The oil is of medium age if the oil is tested after 6 years. Finally, the oil sample tested after 10 years is named as highly aged.

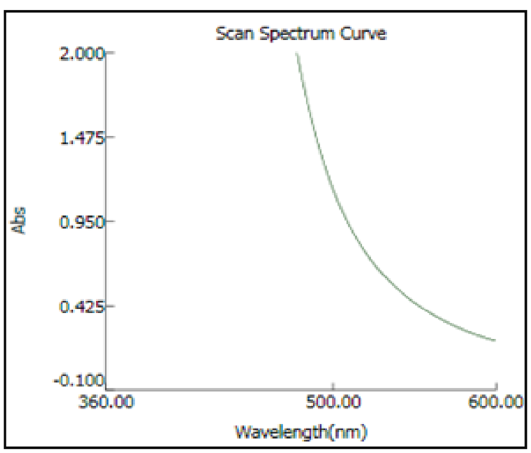


Fig. 6 Highly aged transformer oil

IV. PARAMETER EXTRACTION FOR AUTOMATIC IDENTIFICATION

It is mentioned earlier that a decision tree has been used for automatic identification. A decision tree requires input values based on which an output is obtained. The input value to the decision tree generally is based on any of the parameters related to the problem statement. In the present work the information about the age is obtained UV spectrophotometer plot between absorbance and wavelength parameters. Out of these the absorbance values are used for the input to the decision tree. The parameter is chosen because the value of absorbance varies with the type of impurities present in the oil. The initial values will be different for various oil samples. The values may be same for different samples but the wavelength will be different. Such type of information is useful and ultimately important for automatic identification.

For extracting the information required eight different samples of oil have been considered. The oil samples are collected from different transformers located at distant places and of different aging. Each and every sample is then scanned by the UV instrument to get the spectrum. The procedure is followed as discussed in section III. The obtained plots have already been shown in Fig. 3 to 6. The data is also stored parallel with the plot. These values are then transferred to MATLAB environment to calculate the performance index (P.I) and heptane index (H.I). The calculated performance index is based on the absorbance values of all the samples obtained. The detail about the calculation of PI is discussed as below.

P.I= (MEAN ABSORBANCE VALUE OF EACH SAMPLE)*100

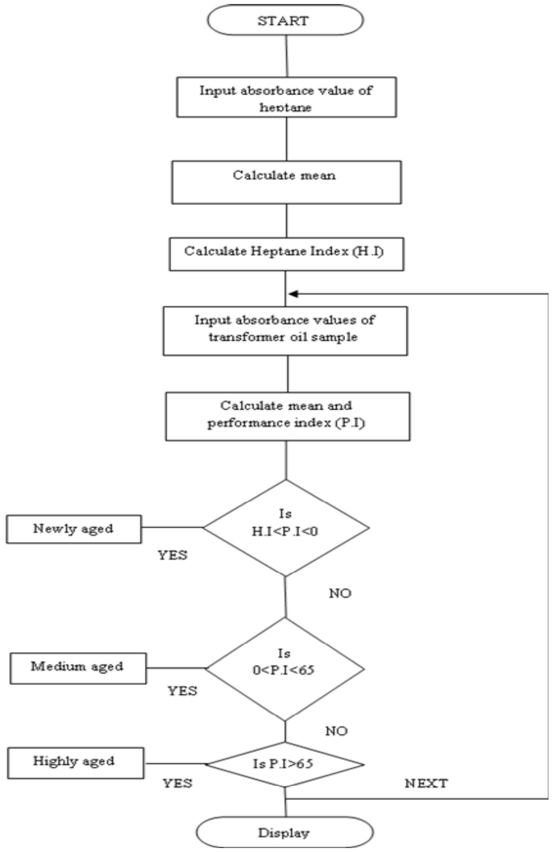
H.I= (MEAN ABSORBANCE VALUE OF HEPTANE SAMPLE)*100

where, P.I = performance index for all the oil samples and

H.I= performance index of heptane.

TABLE I EXTRACTED FEATURES FROM THE ABSORBANCE VALUES OF THE UV SPECTROPHOTOMETER

S No.	Type Of Sample	P.I/H.I
1	heptane	-8.2
2	New oil	-8.2<P.I<0
3	Medium aged oil	0<P.I<65
4	Highly aged oil	65<P.I



The H.I is used as the reference for identification of age of the oil samples used. The UV spectroscopy of heptane is used as the base line to plot the UV scan of the other oil samples. Hence, here the heptane index (H.I) is used for making the decision about the age of the oil. The details about the P.I and H.I extracted is tabulated and presented in Table I. The implementation and structure of decision tree is discussed in the next section.

V. DECISION TREE IMPLEMENTATION AND RESULTS

Based on the obtained values of the P.I and H.I a decision tree has been designed and implemented. The logic flow of the decision tree is shown in the flowchart in Fig. 7. The decision tree is based on similar operations of a flowchart and IF logics. Initially the Heptane Index (H.I) is calculated to form the base index. Then the performance index (P.I) of each and every sample is calculated. From a complete observation of all P.Is and UV plots a common conclusion has been drawn. It is found that if the value of the P.I is lying between the H.I value and 0 then the oil sample is new. The exact age in years is not obtained but the information whether the oil is brand new or of medium age or very old can be gathered.

Sl. no	Type Of Sample	Mean Abs	P.I/H.I
1	heptane	-0.082	-8.2
2	new oil sample 1	-0.013625	-1.3625
3	new oil sample 2	-0.0345	-3.45
4	new oil sample 3	-0.053	-5.3
5	med agd oil s1	0.512625	51.2625
6	md agd oil s2	0.157	15.7
7	High agoil s1	0.894125	89.4125
8	High agoil s2	0.88775	88.775

If the value of P.I is such that it is greater than 0 and lesser than 65 then the oil is of medium age. If the P.I is not satisfying any of the condition mentioned above then the oil is of very old age. These logical outputs form the decision tree output. The values of different P.I obtained for various samples is shown in Table II. The table contains the values of P.I of all the samples with their mean absorbance values. The P.I values of Table II are now fed to the decision tree to obtain the outputs. The structure of the decision tree is shown in Fig. 8. The decision tree structure has four levels. Level 1 and level 2 is meant for taking the inputs and calculating the P.I. Following these level 3 checks the designed conditions. Based on the validity of the conditions in level outputs are obtained in 4th level of the tree.

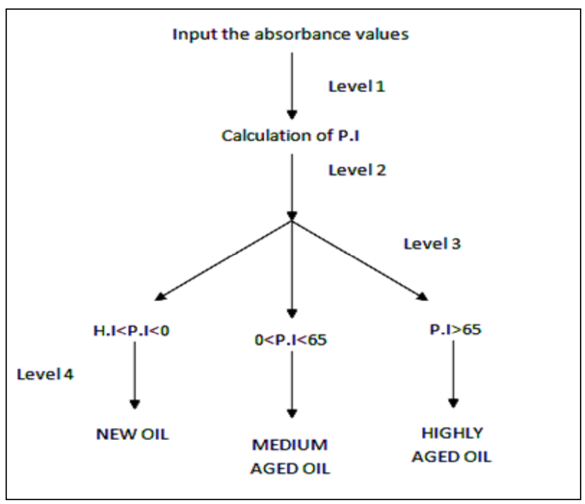


Fig. 8 Decision tree structure implemented for identifying the age of the oil

The results obtained from the decision tree are shown in Table III. The accuracy of the decision tree based on the UV spectroscopy is clearly visible. All the results obtained using the UV/VIS and decision tree are same. It is seen that the proposed methodology is highly accurate and efficient in identifying the age of the sample.

TABLE III : COMPARISON OF DECISION TREE AND UV SPECTROPHOTOMETER RESULTS

S. No	Type of Sample	UV/VIS Result	Decision Tree Result
1	Heptane	Heptane	Heptane
2	Sample 1	New Oil	New Oil
3	Sample 2	New Oil	New Oil
4	Sample 3	Med Aged	Med Aged
5	Sample 4	High Aged Oil	High Aged Oil
6	Sample 5	Med Aged Oil	Med Aged Oil
7	Sample 7	High Aged Oil	High Aged Oil
8	Sample 8	New Oil	New Oil

VI. CONCLUSIONS

In this paper, decision tree method based on UV Spectrophotometer absorbance values is used for automatic health assessment of the transformer oil. Various samples of oil have been taken and the curve is a plot through which the condition of oil is determined. The outputs obtained from the decision tree method are compared with the UV/VIS response. It is found from comparison that all the results obtained from decision tree are same as obtained from the UV spectrum. The results obtained are very efficient and fast. Such information is highly needed for a person at the monitoring point.

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