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ANFIS Based Approach to Estimate Remnant Life of Power Transformer by Predicting Furan Contents

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ABSTRACT

A Condition monitoring and diagnostic playing important role in estimating remnant Life of power transformer. Concentration of furan content in transformer oil can be a promising factor for indirect measurement of the aging of transformer insulation. The oil gets contaminated mainly due to prolonged operation and ageing. The present research paper introduces Adaptive Neuro Fuzzy inference system (ANFIS) technique to correlate furanic compounds obtained by High Performance Liquid Chromatography (HPLC) test to remnant life of the power transformer. The results are obtained by conducting HPLC test at TIFAC-CORE lab, NIT Hamirpur on thirteen samples of Power transformer oil taken from Himachal State Electricity Board Ltd, Shimla (India).

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1. INTRODUCTION

The solid insulating materials used in transformers are mostly made up of cellulose materials viz. insulating papers, pressboards, and so on. These insulating materials must have high dielectric strength and high tensile strength as per IS/IEC standard in respect to concerned KVA class of power transformer. However, these materials get gradually degraded due to electrical and thermal stress that decreases the Thermal stress handling capability and the dielectric strength of the cellulose material in a composite insulation system of the transformer. Due to the degradation of cellulosic material in the form of weakening of intermolecular bonding, there is substantial decrease in the tensile strength of the insulation system composed of the cellulosic material. The transformer may gets failed upon witnessing rated or below rated short-circuit force [1, 2]. Thus ultimately, the life of transformer is severely affected by this weak intermolecular bonding of composite insulation system material. When degradation of paper insulation occurs, the cellulose molecular chains gets shorter and chemical products such as furanic compounds are produced and get dissolved in the oil. Oil-impregnated cellulose is degraded due to three main mechanisms; hydrolytic degradation, oxidative degradation (pyrolysis mechanism) and thermal degradation. Concentration of furan content in transformer oil reveals an indirect measurement of the aging of transformer. Furan content measurement consists of measuring five furfurals dissolved in transformer oil that differ in their stability i.e. 2-furfural (2-FAL), 2-Furfurol (2-FOL), 5-Hydroxy methyl-2-furfural (5-HMF), 5-Methyl-2-Furfural (5-MEF) and 2-Acetylene (2-ACF). Generation of this furanic compound depends upon the level of deterioration of cellulosic insulation system [3, 4, 5, 6, 7, 8].

Furans are the major products which emanates from degradation of paper insulation in transformer oil and the most prominent component of paper decomposition in oil is 2-FAL. Increase in Furan concentration in transformer oil indicates decreases in the tensile strength and the degree of polymerization (DP) of the paper. Furan level in a transformer can be correlated with paper DP, and thereby, an in-service assessment of the mechanical strength of the paper insulation can be estimated. De Pablo reported the relation between 2-FAL and degree of polymerization (DP_V) based on viscosity of oil as [9],

$$DP_V = \frac{7100}{8.88 + 2FAL} \quad (1)$$

Where, 2-FAL is the furfural concentration in mg/kg or ppm of oil. Table 1 shows the correlation between 2-furaldehyde (2-FAL) and DP with respect to the solid insulation extent of damage depicting significant on paper insulation dielectric and mechanical properties.

Table 1. Correlation between 2-FAL and DP.

2-FAL (ppm)	DP value	Health condition
0-0.1	1200-700	Healthy Insulation
0.1-1.0	700-450	Moderate Deterioration
1-10	450-250	Extensive Deterioration
>10	<250	End of life

New paper under normal aging condition produces Furfural at a rate of 1.7mg/g of paper /h and as the aging of transformer occurs this rate of generation is substantially increased by 05mg/g of paper, indicating extensive degree of deterioration and end of life approximately 15 to 20 years [12].

When 2-FAL value is greater than 10 and DP test reveals a value less than 250, the insulating paper is considered to have lost all its mechanical strength, and the transformer life has reached its end of life criteria. Furans concentration is measured by High-Performance Liquid Chromatography (HPLC) or Gas Chromatography-Mass Spectrometry (GC/MS) based on American Society for Testing and Materials (ASTM D5837, Standard Specifications for Mineral Insulating Oil in Electrical Apparatus).

This research paper presents a novel approach for estimating the remnant life of power transformer using furan concentration in transformer oil. Results show that there is a good correlation between furan concentration level in oil transformer and its estimated life. The rest of the paper has been organized as follows: Section II discusses the furan analysis and the test conducted on the transformer oil. Section III discusses proposed ANFIS model to estimate remnant life of transformers. Results and discussion are given in section IV and finally conclusions are drawn in section V of the paper.

2. FURAN ANALYSIS BY HPLC

Furan is used to determine the degradation of the solid insulation like paper, pressboard etc. According to ASTM D-5837 the furan analysis is performed by the High Performance Liquid Chromatography (HPLC). The lab set up for performing High Performance Liquid Chromatography (HPLC) to estimate furan contents is shown in Figure 1.

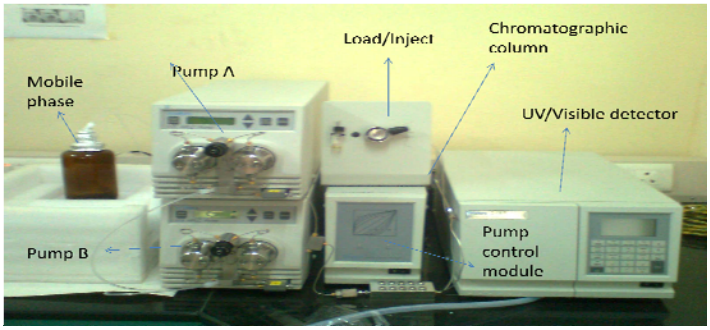

Figure 1. Lab set up for HPLC to find furan compounds

HPLC has mobile phase and stationary phase and the detector used to detect furans is UV visible detector. The detector detects specific wavelength and peak absorbance of transformer oil. Furan content measurement consists of measuring five furfurals dissolved in transformer oil that differ in their stability. Furfurals are composed of 2-furaldehyde, 5-hydroxymethyl-2-furaldehyde, 2-furoic acid, furfuryl alcohol, 5-methyl-2-furaldehyde and 2-acetyl furan compounds. 2-furaldehyde (2-FAL) is the most stable compound for measurement; however, all other furan compounds, except 2-furfuryl alcohol, are detected in insulating oil up to 140℃.

Each furanic compound has a characteristic maximum light absorbance occurring within the indicated ranges of wavelengths. To detect the specific wavelength for furanic compounds, use of variable wavelength or diode array detector is necessary. The specific wavelength is selected to yield maximum absorbance for each compound. Results show that absorbance and wavelength increases by a significant and easily observable margin as deterioration and contaminations of transformer oil increases, which are reflected by the furan concentration level in the oil.

The experiment has been performed on new, medium and highly aged transformer oil. If the oil which is not in commission or of about 1 year age and if the furan content is very low in range 0-0.1ppm then it is categorized as new oil. The oil which is tested after 6 to 7 years and the furan content is in range 1-7ppm than it is categorized as medium aged oil. Finally, It has been found that in case, the oil sample tested after 9 to 10 years or more and furan contents are greater than 10ppm it is categorized as highly aged and it is required to be monitored.

3. TRANSFORMER LIFE ESTIMATION TECHNIQUE

In the present work, Adaptive neuro-fuzzy inference system (ANFIS) based technique is proposed to estimate the remnant life of power transformers and its correlation to the furan contents present in the transformer oil obtained by HPLC spectral response. The detail of the technique used is given below and the results are discussed in later section. In ANFIS sugeno type fuzzy logic method is used which is, computationally effective and works well with optimisation and adaptive techniques. Wavelength (nm) and the maximum absorption (nm) are the inputs for the ANFIS model, which are recorded for different transformer oil samples. The corresponding ANFIS simulation model developed is shown in Figure 2.

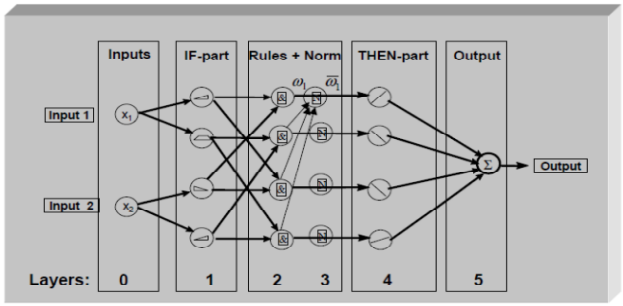

Figure 2. ANFIS network [10]

The output of the model is the furan contents and corresponding estimated remnant life. The model is built using the graphical user interface tool provided by MATLAB [11]. Each input is fuzzified into ten sets [12] of Gaussian combination membership function (MF) governed by the equation (2)

$$f(x,c,s,m)=\exp\left[-\frac{1}{2}\left(\frac{x-c}{s}\right)^{m}\right] \quad (2)$$

where ‘c’ is centre, ‘s’ is width and ‘m’ is Fuzzification factor. The function set developed for each input is a combination of s and c parameters.

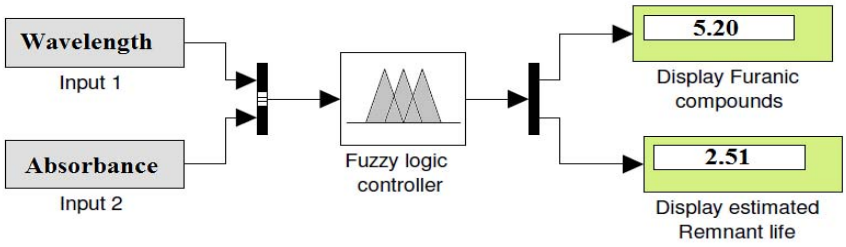

Figure 3. ANFIS model to estimate furan contents and remnant life of power transformers.

Result of fuzzification from each input is then applied with fuzzy operator in the antecedent and related to the consequence, by IF-AND-THEN application method [13-14]. The output of sugeno model is obtained by the weighted average (WA) of the singletons in the outputs.

4. RESULTS AND ANALYSIS

The discussion can be made in several A total number of thirteen power transformer oil samples are taken from Himachal State Electricity Board Ltd, Shimla (India) for the research and the study purpose. These transformers are of different manufacturing companies' viz. General Electric Company, Crompton and Greaves and Computing Tabulating Recording (CTR) having different installation year, MVA ratings varies from 5-50 MVA, different KV ratings varies 6.6-133 KV. Using High Performance Liquid Chromatography (HPLC) the transformer oil samples were tested at TIFAC-CORE lab, NIT Hamirpur (H.P) and the obtained results are given in Table 2. When the furan content of the transformer oil is more than 10ppm or the wavelength is more than 430nm that means transformer has end his life criteria. The ANFIS model developed using Matlab graphical user inference is with the accuracy of more than 98%.

Table 2. Result of HPLC and ANFIS model

Tran. No.	Wavelength (nm)	Absorbance (nm)	Furan (ppm)	ANFIS output	Corresponding Remnant Life (years)
1	321.31	1.240	0.00	0.076	40.0
2	334.40	1.280	0.47	0.393	36.4
3	342.80	1.390	0.97	0.861	27.4
4	359.10	1.440	1.43	1.120	15.9
5	363.80	1.510	3.12	3.060	6.75
6	388.90	1.620	4.21	4.160	3.24
7	397.80	1.701	5.33	5.210	2.5
8	410.21	1.721	8.28	8.25	1.84
9	424.58	1.791	9.22	9.07	1.26
10	442.60	1.810	13.08	13.3	0.602
11	457.20	1.874	14.01	14.00	0.438
12	460.80	1.901	15.00	14.80	0.0
13	472.10	1.971	16.78	16.80	0.0

Comparing the results obtained in Table 2 by those limits in Table 1, the transformer life estimation can be obtained from the wavelength of the transformer oil spectral response as shown in Table 3.

Table 3. Correlation between wavelength and DP

Wavelength (nm)	DP value	Significance on paper insulation
290-330	1200-700	Healthy Insulation
330-345	700-450	Moderate Deterioration
345-430	450-250	Extensive Deterioration
>430	<250	End of life

The membership function plot for the input wavelength and absorbance used in ANFIS model is shown in Figure 3 and Figure 4 respectively. All the membership functions are fuzzified into ten sets so that the desired output is satisfied according to the input and output. The rules developed to predict furans and to estimate remnant life is shown in Figure 5. The three dimensional graph between wavelength, absorbance, furan contents and remnant life is shown in Figure 7 and Figure 8 respectively.

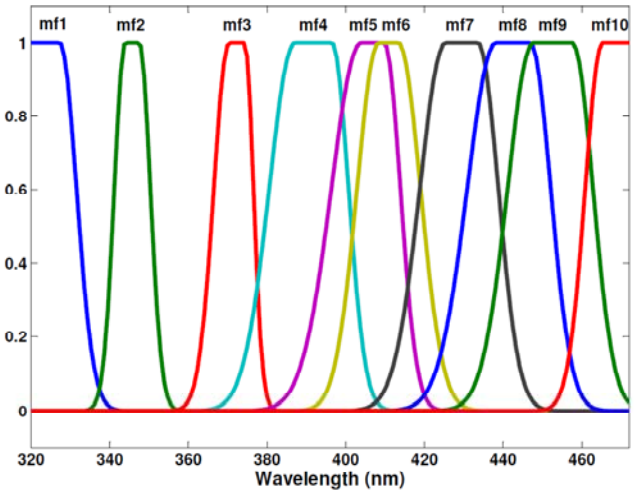

Figure 4. Membership function plot for wavelength

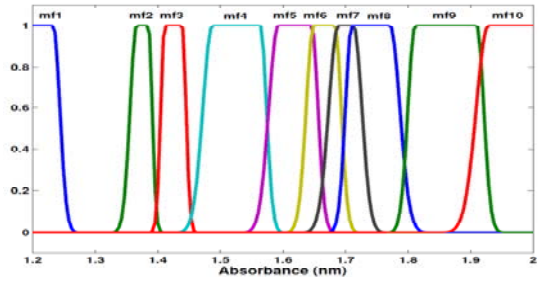

Figure 5. Membership function plot for absorbance.

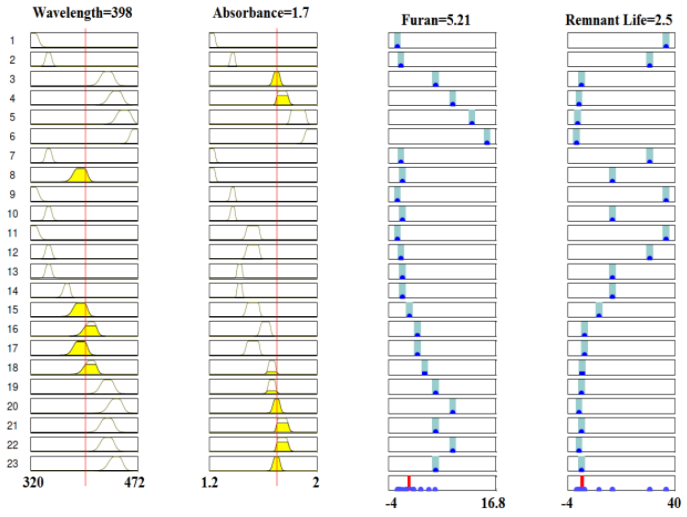

Figure 6. Rules developed to find the furan contents and remnant life of transformers.

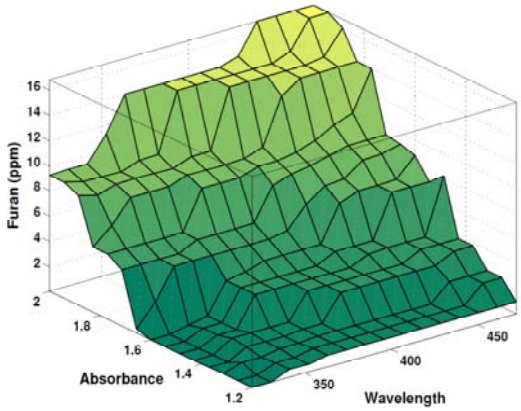

Figure 7. 3D graph between wavelength, absorbance and furan contents of transformer.

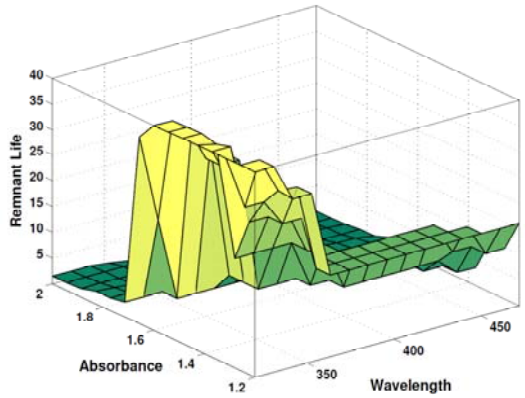

Figure 8. 3D graph between wavelength, absorbance and remnant life of power transformer.

5. CONCLUSION

The present research paper introduces a novel Adaptive neuro fuzzy inference system (ANFIS) approach to correlate the estimated transformer remnant life and the furan results with the help of spectrum analysis shown in Figure 8.

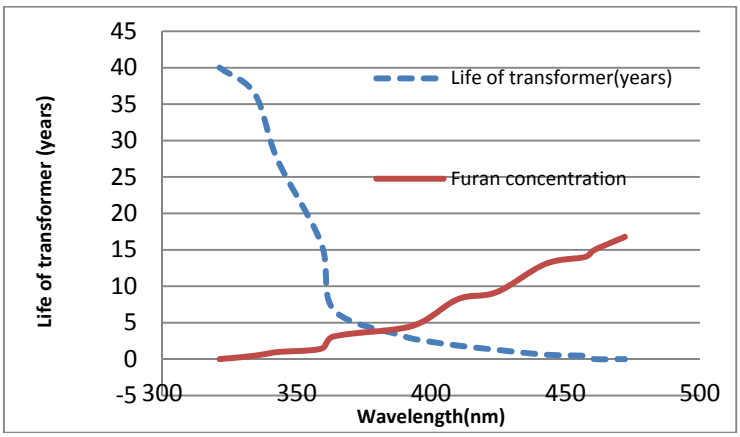

Figure 8. Relation between Life of transformer (Years) and Furan concentration Vs wavelength (nm)

It is found from comparison that all the results obtained from ANFIS model is almost equal to the results obtained by HPLC. The transformer life criteria ends when the wavelength is more than 430nm or furan contents increases more than 10ppm. The models developed have accuracy of more than 98 percent. It is also obvious that approach is free from chemical treatment and less time consuming.

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