Assessment of Health Index of oil immersed Power Transformer Using Artificial Neural Network

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ABSTRACT—Power transformers are used for step up or step down the voltage level in the transmission network. Determining the existing condition of the transformer is still a challenge and many researchers are involved in predicting it. In this paper a novel system based on neural network is developed which predicts the health index of the transformer by considering thermal, electrical, physical and chemical properties prevailing in the transformer and gives the current status of the transformer. Health index of a transformer combines the results of various routine inspections, and laboratory testing to estimate the insulation. Among various analysis done on power transformer which includes Dissolved Gas Analysis, Furan Analysis, analysis of oil characteristics etc., conductivity factor and the polarization index strongly influence the health of power transformer. By calculating the health index, the characteristics of its insulation system is analyzed and hence the condition of a power transformer and remaining lifetime of the transformer can be assessed.

Index Terms—*Dissolved Gas Analysis (DGA), Interfacial tension (IFT), neural network, conductivity factor, polarizing index*

I. Introduction

In practice, Power transformers are designed to operate for 30-40 years but if proper maintenance is performed, the transformer life can be extended to 60 years [1]. Hence monitoring and diagnosis of insulation system of the transformer is necessary. Health index (*HI*) is a tool that helps to evaluate the general condition of a power transformer. Based on a wide variety of physical, electrical, mechanical, thermal effects different methods of monitoring and diagnosis are used. Assessing the transformer health index helps us to know its insulation quality and represents only the level of long-term degradation, a condition that cannot be determined by routine inspection [4], [5] but does not provide the status of any particular part of a transformer incase of repair. In order to calculate the health index, diagnostic factors related to transformers are considered. In this paper various standards are considered to calculate the health index of a transformer insulation system (dissolved gas analysis, oil quality, furans content, dielectric loss factor and conductivity factor.

II. HEALTH INDEX

Health Index [1] - [3] is a useful tool that combines all of the current information about a transformer and provides a single quantitative index that represents its overall health. Health Index (*HI*) is a size which can be used to evaluate the general condition of a power transformer. This size is calculated using some of the most representative elements of diagnosis (or state) that characterize the operation and status of the transformer. In this paper various factors such as Dissolved Gas Analysis, Oil Quality Factor, conductivity factor, polarizing index, loss factor, and furan content are considered as the representative elements of diagnosis. In [3], a relation for calculating the health index is proposed, namely.

$$HI_I = A_1 \frac{\sum_{i=1}^{n} C_I DI_I}{\sum_{i=1}^{n} C_i} \quad \text{.............................. 1}$$

Where,
C_I is the rating given to each state factor.
DI_I is the value of the diagnostic index.
n is the number of considered diagnostic factors
A_1 IS the corresponding weights of *n* factors that describe the transformer state. In the upcoming chapters, the calculation model of diagnostic index (*DI*) is shown for several diagnostic factors proposed for calculating the health index. The state factor and diagnostic index for each diagnostic factor is given in the table 1.

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Table 1: Diagnostic factors used to calculate the Health Index.

s. no	Diagnostic factors	C_i
1	Dissolved Gas Analysis (DGA)	10
2	Oil quality	6
3	Furans content	5
4	Conductivity factor k_c	10
5	Polarization index k_p	10
6	Loss factor	10

III. Dissolved Gas Analysis

Dissolved Gas Analysis is widely used most powerful method to detect incipient faults on oil filled electrical equipment .The electrical equipment may be a transformer, a load tap changer or a cable [1]-[3].

The various inter -turn fault identified by the DGA in the power transformer is partial discharge, thermal fault and electrical fault. The faults in the transformer produces energy that is needed for breaking the chemical bonds and generate the gases which includes hydrogen H_2 , methane (CH_4), ethane (C_2H_6), ethylene (C_2H_4), acetylene (C_2H_2), carbon dioxide (CO_2)and carbon monoxide (CO).The gases listed above are generally referred to as key gases. Based on the gases observed, the faults are classified. Various methods are available namely Rogers method, key gas ratio, Duval triangle etc. among all methods Duval triangle is mostly preferred .The Dissolved Gas Analysis Factor (DGAF) is calculated using the formula (2).

$$DGAF = \frac{\sum_{n=1}^{7} n_i p_i}{\sum_{n=1}^{7} p_i} \quad \text{.......................................2}$$

Where,

n_i = scoring factor

p_i = weighting factor.

The scoring factor and weighting factor of various gases generated under different condition based on standard IEC-599 is given in the table 2.

Table 2: weighting and scoring factor for various dissolved gases based on standard IEC-599

IEEE Risk Condition	HI factor	Hydrogen H_2	Methane CH_4	Acetylene C2H2	Ethylene C_2H_4	Ethane C_2H_6	Carbon Monoxide CO	Carbon Dioxide CO_2
	Weighting factor / Scoring factor	**2**	**3**	**5**	**3**	**3**	**1**	**1**
Condition 1	1	100	120	1	50	65	350	2500
Condition 2	2	101-200	121-400	2-9	51-100	66-100	351-570	2500-3000
Condition 3	3	200-400	401-700	10-20	101-150	101-125	571-1200	3001-4000
Condition 4	4	400-700	700-1000	20-35	150-200	125-150	1200-1400	4000-5000
Condition 5	5	>700	>1000	>35	>200	>150	>1400	>700

IV. Oil characteristics

Oil characteristics such as oxygen content, Interfacial Tension(IFT), acidity, Dissipation Factor (DF), dielectric strength, etc., indicate the state of the oil used for insulation[6]-[8].

Due to the presence of transformer moisture dielectric characteristics of the insulation system gets lower. Interfacial tension between the electro-insulating liquid and water quantifies the attraction forces between molecules at the separation interface between two different environments. Oil quality factor is calculated based on the scoring factor and weighting factor of various oil characteristic given in the

V. Loss factor

Due to intensified orientation and interfacial polarization, ionic conductivity growth, increased dispersion processes (at low frequencies) and "ionic dipoles" forming processes (due to alternating displacements of ions having opposite signs), the existence of degradation products can be more clearly highlighted, at lower frequencies can be highlighted by loss factor . From [4], Diagnostic index of loss factor DI_{lf} *values* are taken and illustrated in table 4.

Table 4: Diagnostic index DI_{lf} *corresponding* to the loss factor

Diagnostic Index DI_{lf}	Loss factor	State
1	≤ 2	Good
2	2 - 5	Satisfactory
3	5 -20	Poor
4	20 - 100	Very poor
5	>100	Dangerous

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VI. Conductivity Factor

Conductivity factor of oil can be calculated using the formula (3).

$$K_c = \frac{i(30)_a - i(30)_r}{i(60)_a - i(60)_r} \quad \text{.............................3}$$

Where $i_{a,r}$ (30, 60) represent the values of absorption/desorption currents measured at 30 and 60 s from the applied voltage start [8]. Total electrical Conductivity State of oil based on its degradation can be estimated by conductivity. Diagnostic index of conductivity factor DI_c referred from [4] is given in the table 5.

Table5: Diagnostic index DI_c corresponding to the Conductivity factor.

Diagnostic index DI_c	k_c	State
1	$k_c \le 1.4$	Good
2	$1.4 > k_c \le 1.3$	Satisfactory
3	$1.3 > k_c \le 1.2$	Poor
4	$1.2 > k_c \le 1.1$	Very poor
5	$k_c \le 1.1$	Dangerous

VII. Polarization Index

The polarization index is also calculated using absorption/desorption currents:

$$K_p = \frac{i(60)_a}{i(600)_a}$$

Where i_a (60) and i_a (600) represent absorption current Values measured at 60 s and 600 s from the applied Voltage *U* start [6]. From [4], diagnostic index of polarizing index DI_p values are taken and given in table 6.

Table 6: diagnostic index DI_p corresponding to polarizing index

Diagnostic index DI_p	k_p	State
1	$k_p \le 2$	Good
2	$1.25 \le k_p < 2$	Satisfactory
3	$1.1 \le k_p < 1.25$	Poor
4	$1 \le k_p < 1.1$	Very poor
5	$k_p < 1$	Dangerous

VIII. Furans Content

Assessment of solid component states of the power transformers insulation systems (PTIS) and oil-impregnated paper can be done using furan content analysis. The diagnostic values of furan content are taken from [4] and given in the table 7.

Table 7: Values of the diagnostic index DI_f corresponding to furans content

Diagnostic index DI_f	Furans content [ppm]	Transformer life [years]
1	0 – 0.1	< 20
2	0.1 – 0.25	20 – 40
3	0.25 – 0.5	40 – 60
4	0.5 – 1.0	> 60
5	> 1.0	…

Size/ U_n	69 kV < U_n < 230 Kv	Score (n_i)	p_i
Dielectric strength (kV/mm) (2 mm)	≤ 52	1	3
	47 – 52	2	
	35 – 47	3	
	≤ 35	4	
Interfacial tension (dyne/cm)	≤ 30	1	2
	23 – 30	2	
	18 – 23	3	
	≤ 18	4	
Acid number	≤ 0.04	1	1
	0.04 – 0.1	2	
	0.1 – 0.15	3	
	≤ 0.15	4	
Water content (ppm)	≤ 20	1	4
	20 – 25	2	
	25 – 30	3	
	≤ 30	4	
Dissipation factor at 50 Hz	≤ 0.1	1	4
	0.1 – 0.5	2	
	0.5 – 1.0	3	
	>1	4	

IX. Results and Discussion

In this paper, the condition based diagnosis system developed to combine six diagnostic tests performed on transformer oil to evaluate health index of power transformer.

Neural network approach in this contest is used for classifying data organized by the level of its uncertainty. About 15 neural network controllers were developed in MATLAB based on various standards. Dissolved Gas Analysis Factor has been estimated by combining scoring factor of the neural network models of key gases along with their respective weighting factor using the formula 2 . Oil Quality Factor is estimated by combing the scoring factor of neural models of oil characteristic along with their respective weighting factor using the formula 2. Polarizing Index, Conductivity Factor, Furan Content and Loss Factor are trained as the separate neural model. Each neural network is constructed with single hidden layer that consist of 10 hidden neurons is used for the assessment. For this analysis, 360 real time data samples from power transformers across Tamilnadu are preferred for training the networks of key gases and oil characteristics. Network model of Polarizing Index, Conductivity Factor, Furan Content and Loss Factor are trained by selecting 30 samples for each case from their respective tables.[9-11] Each diagnostic factor along with their state factor, are combined to calculate the final health .The condition of transformer health based on the rating is given in the table 8. Using the health index, the condition of a power transformer can be assessed. This factor allows the estimation of remaining transformer lifetime, by considering some of the most important characteristics of its insulation system. The expected lifetime of the transformer based on the Health Index calculated is given in the table 8. The health index is strongly influenced by the dielectric losses which occur inside electro-insulating components volumes, but also by the conductivity factor and the polarization index. The estimation of DGAF, OQF, HI and lifetime estimation for the testing samples considered are given in the table [9-11].

Table 8: Expected lifetime estimation using HI

HI	Transformer condition	Expected lifetime
1	Very good	> 15 years
2	Good	> 10 years
3	Satisfactory	< 10 years
4	Poor	< 3 years
5	Very poor	End-of-life

Table 9: calculation of DGAF for testing samples

S.No	Sample 1	Sample 2	Sample3	Sample 4	Sample 5
H_2	800	150	60	300	400
CH_4	900	350	80	1200	700
C_2H_2	33	6	0.4	17	20
C_2H_4	170	78	20	600	100
C_2H_6	140	69	40	22	101
CO	130	500	100	300	1200
CO_2	450	3000	300	1000	400
DGAF	**4.059**	**1.945**	**1.005**	**2.78**	**3.068**

Table 10: calculation of OQF

S. No.	Sample1	Sample2	Sample3	Sample4	Sample5
Acidity	02	0.09	0.005	0.001	1
BDV	33	47	52	2	37
water	40	22	5	26	24
IFT	17	25	40	3	20
DF	2	0.2	0.001	0.01	0.8
OQF	**3.911**	**1.89**	**1.11**	**2.722**	**2.77**

Table11: Estimation of Age of Transformer Based on Health Index

S. No	DGAF	OQF	DI_{lf}	DK_p	DK_c	DK_f	HI	ET
1	4.05	3.91	4	3	3.9	3.99	4.0	< 3 years
2	1.94	1.89	1.8	1.9	2.1	1.6	1.9	< 10 years
3	1.00	1.11	1.2	1	1	1.15	1.0	> 15 years
4	2.18	2.72	1.1	1.0	4	3.99	2.4	> 10 years
5	3.06	2.77	2.7	2.5	9	3.97	3.1	< 10 years

X. Conclusion

The composite Health Index presented in this paper is a very useful tool for representing the overall health of a complex asset such as a power transformer.

Based on numerous condition criteria that are related to long-term degradation factors HI quantifies equipment's health[12],[13]. In this multi-criteria analysis approach various factors are combined into a condition-based HI. DGA, Water content, BDV, IFT, furan analysis were used as inputs for training the neural network to calculate transformer health index. By Health Index calculation, the transformer life can be extended, and the risks are eliminated. The satisfactory operation of large power transformers can be achieved only if the condition of the coolant oil is maintained. The neural network has been proposed in this work due to its simplicity and accuracy.

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