International Journal of Computer and Communication Technology

Volume 4 | Issue 3 Article 14

July 2013

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Recommended Citation
Rao, U. Mohan and Jarial, R. K. (2013) "A Novel Fuzzy Logic Based Technique to Find the Criticality of Power Transformer," *International Journal of Computer and Communication Technology*: Vol. 4 : Iss. 3 , Article 14.
DOI: 10.47893/IJCCT.2013.1199
Available at: https://www.interscience.in/ijcct/vol4/iss3/14

A Novel Fuzzy Logic Based Technique to Find the Criticality of Power Transformer

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***Abstract*— Determining the current prevailing conditions in the transformer is still a challenge and an attempt is made for meeting the same challenge. In this paper a novel system based on fuzzy logic is developed which considers thermal, electrical and mechanical conditions prevailing in the transformer and gives the critical status of the transformer at an aggregate. The developed system also facilitates to give the critical condition of Paper thermal, Oil thermal, Partial discharge, Electrical arching, Dissolved gas analysis(DGA), Break down voltage and sweep frequency response analysis(SFRA) individually so that corresponding preventive measures can be taken by the technologists. This system consists of 10 fuzzy logic controllers whose connections are made by considering technical conditions and reasons, the corresponding rule bases of these fuzzy logic controllers were developed by considering various standards and experience of TIFAC CORE in NIT-Hamirpur. This fuzzy logic based system is tested for various transformers and found that it is highly précised in classifying the critical statues of any transformer as well as all identifying the current prevailing conditions.**

***Index Terms*— criticality, fuzzy logic controller, membership functions, rule base, transformers**

I. INTRODUCTION

Transformers being one of the most important equipment in the electrical power systems environment and requires a good maintenance with an approach of efficient condition monitoring techniques and diagnostic tools. Précised tools and techniques are yet a challenge in the research area of condition monitoring of power transformers. DGA as one of the most powerful tool in this area survives these days with many interpretation techniques like Key gas method [1], Duval triangle method [2], Rogers ratio method [3-4]. But the major problem with these tools is that it relies on experience more than mathematical formulations and even many a times a situation occurs where DGA fails to characterize the fault as the interpreted values falls out of the standard ranges. DGA facilitates to determine transformer failure rank and impact on its aging [5]. But it is well believed that some particular gases are evolved with decreasing in the heat dissipation ability of insulating oil and paper during faults due to increased thand electrical stresses. Gases produced due to oil decompositions are hydrogen (H_2), methane (CH_4), acetylene

(C_2H_2), ethylene (C_2H_4) and ethane (C_2H_6) and paper decomposition produces carbon monoxide (CO) and carbon dioxide (CO_2) [6]. Carbon monoxide (CO) and carbon dioxide (CO_2) are well known for revealing paper degradation related faults, ethylene (C_2H_4) and ethane (C_2H_6) are significant in indication with increased oil temperature, partial discharge being low level energy produces hydrogen (H_2), methane (CH_4), arcing can be identified by observing the evolution of acetylene (C_2H_2), hydrogen (H_2) [6]. On the other side of coin break down voltage (BDV) insulating of oil plays as an important parameter for determining the dielectric

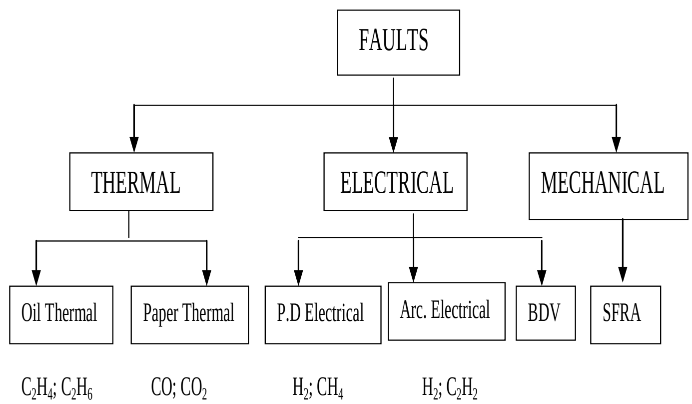

Fig 1.Main types of internal faults

strength of insulating oil and gives a significant indication of oil degradation. So internal catastrophic failures related to thermal faults can be investigated by sub dividing thermal failures as oil thermal faults and paper thermal faults. Similarly electrical related failures can be investigated well by subdividing the faults as PD electrical faults and arcing faults. This is clearly shown in Fig. 1. Mechanical faults even have a major contribution to the internal faults which leads to severe losses to the unit. These mechanical faults such as winding and core deformations can be traced by sweep frequency response analysis (SFRA) [7-8]. Now it is clear with the internal faults, their types and corresponding diagnostic approach. In this paper a new fuzzy logic based system has been developed which gives the overall criticality of the transformer on taking DGA [9], BDV, SFRA test values as inputs. SFRA is based on the evaluation of the curve obtained subtracting the present and the reference frequency response graph [10] while DGA, BDV are supplied as obtained from test results.

fuzzy logic controller development

Fuzzy logic approach in this contest is used for classifying data organized by the level of its uncertainty namely normal, low, moderate, high, and critical. About 10 fuzzy logic controllers were developed using fuzzy inference system (FIS) in MATLAB [12] with input and output membership functions as trapezoidal functions defined on the corresponding ranges as explained in further discussions, these ranges are designed by considering previous test data's, sound experience of TIFAC-CORE in NIT-H campus and various standards for each and every defect topology involved in this system. With these ranges a rule base has been developed to discriminate between the entire topology of the uncertainty levels of the particular parameter. This knowledge base is represented to the fuzzy logic controller using conditional statements like IF, AND, THEN, to make a set of rules to correlate input

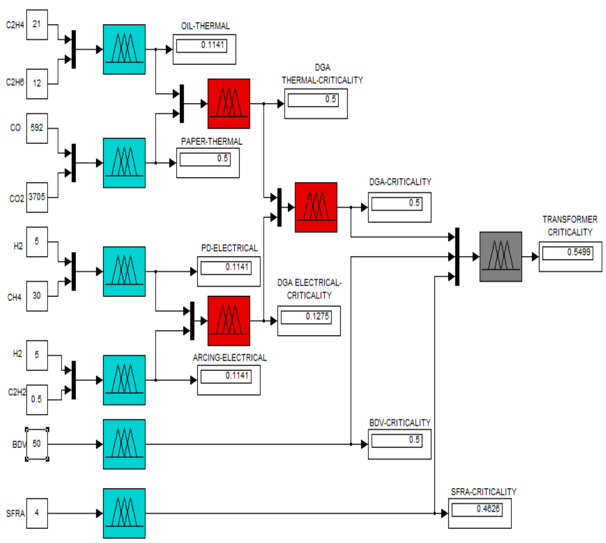

Fig.2 Complete fuzzy model for overall transformer criticality

variables and output variables [11]. The overall fuzzy logic model uses *"MAMDANI FUZZY LOGIC ALGORITHM"* (MFLA) and consists of 10 fuzzy logic controllers as shown in Fig.2. It comprises of 6 fuzzy logic controllers (blue colored) supplied with 10 inputs and 3 fuzzy logic controllers (red colored) in the intermediate level and 1 fuzzy logic controller in the output level (pale colored). This system also facilitates the users to know the Oil thermal, Paper thermal, P.D. electrical, Arcing electrical, BDV, DGA, and SFRA criticalities so that one can know the current prevailing condition in the transformer. One of the sub controllers is explained in detail and the same process is used for the remaining sub controllers involving with DGA. Block sets involved with DGA criticality, BDV criticality, SFRA criticality are also explained in detail with according to their corresponding rule base.

A. Sub fuzzy logic controller

For instance Oil thermal criticality is considered as it is known that ethylene (C_2H_4) and ethane (C_2H_6) are evolved when oil gets decomposed due to raise in oil temperature by reducing the heat dissipating strength of oil. A fuzzy system is developed for finding it with considering a range of 0-200 ppm and 0-150 ppm for C_2H_4 and C_2H_6 respectively. C_2H_4 and C_2H_6 are given as inputs to the fuzzy logic controller as shown in Fig.3 and a rule base is presented to the controller which on simulation gives oil thermal criticality. Trapezoidal membership functions are chosen in developing this fuzzy

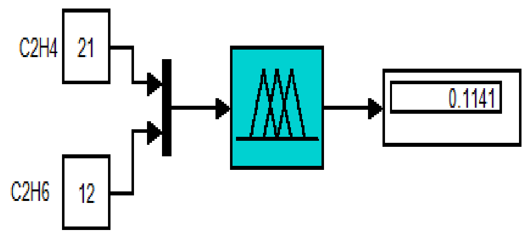

Fig.3 Fuzzy logic controller model for Oil thermal criticality

logic model. Input memberships functions are taken on the ranges said earlier and are established as input variables to the oil thermal criticality logic controller.

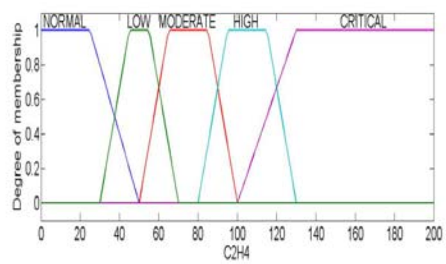

Fig.4 I/P Membership function plot of C_2H_4

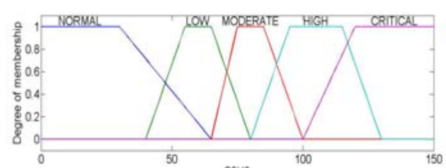

Fig.5 I/P Membership function plot of C_2H_6

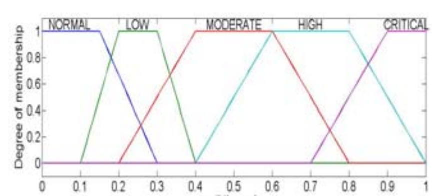

Fig.6 O/P Membership function plot of Oil thermal

These inputs are read according the rule base developed using MATLAB / GUI for fuzzy inference system (FIS). Input and output membership functions are established and are observed as follows for Oil thermal criticality logic controller. Output membership function of Oil thermal criticality is measured on scale of 0-1 in topology of its vulnerable level from normal to critical. This sub system is given with an interpreted test data obtained on performing DGA as $C_2H_4 = 21$ and $C_2H_6 = 12$ and a set of rules were developed which can be observed in rule viewer plot of the system in Fig.7. When the system is simulated it is observed that oil thermal criticality is 0.1141 and found that oil temperature is in normal stage. In the similar way all the sub systems are developed and are connected as shown in Fig.2

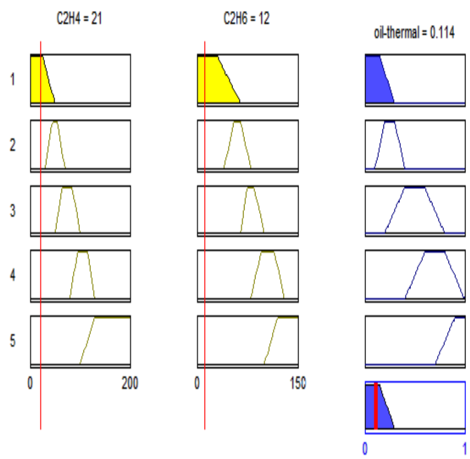

Fig.7 Rule viewer of Oil thermal criticality

B. DGA Criticality

DGA interpreted values are applied as inputs to all the first 8 input constant blocks where input membership variables are considered on different scales like ethylene (C_2H_4) on 0-200ppm, ethane (C_2H_6) on 0-150ppm, carbon monoxide (CO) on 0-1800ppm, carbon dioxide (CO_2) on 0-15000ppm, hydrogen (H_2) on 0-1800ppm, methane (CH_4) on 0-1200ppm, acetylene (C_2H_2) on 0-80ppm with all the output membership functions on the scale of 0-1 for discriminating the level of criticality. These are decided by considering IEC-599 standards and previous experiences. The output membership functions of first two logic controllers gives Oil thermal and Paper thermal criticality which on integration gives DGA thermal criticality. Similarly third and fourth controllers output will be P.D. electrical criticality and Arcing electrical criticality, now on integration of these outputs DGA electrical criticality is obtained. Further for obtaining DGA criticality DGA thermal and electrical criticalities are to be integrated as shown in Fig.2

C. BDV Criticality

Break down voltage of insulating oil is measured and the value is given as input variable to the fifth input logic controller. Input membership function of this variable is defined on a scale from 0-40kv and the output membership function which gives BDV criticality is measured on a scale of 0-1 to give the level of criticality of BDV. This scale is selected by considering ASTM-D877 standards and various test records.

D. SFRA Criticality

Internal mechanical faults are investigated by performing this test. SFRA is based on the evaluation of the curve obtained by subtracting the present and the reference frequency response, this difference is obtained in terms of frequency. 0kz difference indicates that there are no mechanical deformations which is normal, 0-5kHz indicates that core is twisted and is an extent to which disturbance occurred due to failure of ropes or brakes while assembling or installation of the unit, 1-10kHz indicates that there are problems associated with windings, 5-500kHz indicates that there are radial deformations and frequencies > 400kHz indicates axial deformations of every single windings. Input membership function is taken on a scale of 0-400kHz. These scales are considered after a literature survey and experts experiences. The topology of criticality levels are discriminated based on these frequencies ranges. Output membership function is measured on a scale of 0-1 for obtaining SFRA criticality.

E. Transformer over criticality

Overall criticality of a transformer is obtained by integration of DGA criticality, BDV criticality and SFRA criticality. All the three input membership functions and output membership functions are measured on a scale of 0-1 for discriminating the

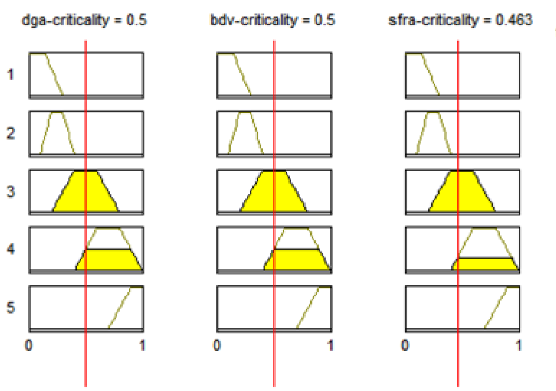

Fig.8 Rule viewer of transformer overall criticality

criticality level of transformer. A rule base is developed to correlate the input and output membership functions and is viewed as shown in Fig.8.over all transformer criticality can be more clearly judged by observing the surface plot shown in Fig.9 by changing the axis parameters.

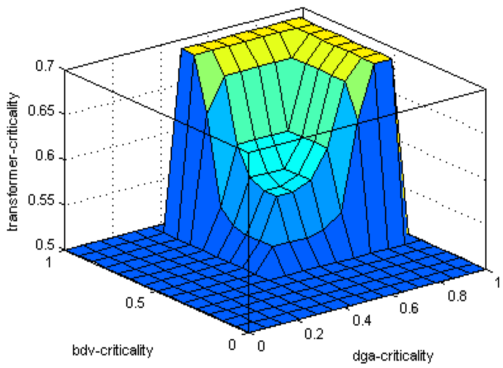

Fig.9 Surface plot of transformer overall criticality

II. SIMULATED MODEL TESTING - A CASE STUDY

This fuzzy logic model is simulated for different previous test results [13] and the criticality of those units are observed, internal displays of Paper thermal, Oil thermal, P.D. electrical, arcing electrical, BDV, SFRA, DGA electrical and thermal criticalities, are obtained and found that these values are in coincidence with the traditional interpreting technique results. For instance a case study is explained in detail. A transformer of 25/31.3 MVA, 132/11 kV is manufactured in the year 2005 and commenced on 22-12-2006 has been tested on 13-04-2010 for DGA, BDV, SFRA and found no mechanical deviations, BDV as 44.14 (according to IS-1866/2000) and on DGA interpretations according to IS-10593/1992 revealed that CO_2, CO, C_2H_4, C_2H_6, CH_4 are in warning stages and on observing these results it was found that the insulating oil is being over heated in the unit. The same results are supplied to the developed fuzzy logic controller model and found the critical values as below

a. Oil thermal criticality: 0.5
b. Paper thermal criticality: 0.5
c. DGA thermal criticality: 0.57
d. P.D electrical criticality: 0.5
e. Arcing electrical criticality: 0.1141
f. DGA electrical criticality: 0.5
g. DGA criticality: 0.57
h. BDV criticality: 0.116
i. SFRA criticality: 0.1141
j. Overall transformer criticality: 0.5

It is observed that oil and cellulose are getting heated more with a criticality of 0.5 and 0.5 resulting DGA thermal criticality to 0.57 and P.D electrical is also pronounced resulting to over all DGA criticality to 0.57, BDV and SFRA criticalities being low gives the overall criticality of transformer as 0.5.this indicates that the unit need not made offline, but care should be taken regarding the aspects of loading and cooling methodologies. Similarly a set of tested samples with its input values and the simulated output values were shown in table-1 and table ii respectively.

TABLE I
INPUT VARIABLES TO THE SYSTEM

I/P	A	B	C	D	E	F	G	H	I
1	90	115	1413	9000	801	400	41	20	100
2	20	55	200	1000	20	80	25	40	0
3	60	55	300	2501	150	100	21	32.5	0
4	75	80	500	3000	700	200	40	28	9
5	200	149	1878	14493	1801	1200	87	20	480

A= C_2H_4, B=C_2H_6, C=CO, D=CO_2, E=H_2, F=CH_4, G=C_2H_2, H=BDV, I=SFRA.

II. FUTURE SCOPE

This system can be upgraded according to the new experiences and constraints if any. The developed fuzzy model even though gives a précised analysis of the results, but it does nothing towards the environmental misleading of the test/result. If the same system is facilitated to intake a set of input variables at a time which should be the test results tested on a few consecutive couple of days then that particular model will be capable of suppressing or reducing environmental impacts on the test/results.

III. CONCLUSION

A novel based fuzzy logic model is developed to discriminate the level of criticality of the transformer in the topology of vulnerability from normal to critical. This model is designed by considering the internal faults related to thermal, electrical and mechanical which are investigated by DGA, BDV and SFRA diagnostic tools. The sensitivity of this model in terms of identifying the Current situations prevaling in the transformer can be increased by considering more number of diagnostic tools. The developed model plays an important role in moving the transformer diagnostics area to a more précised environment without the involvement of any experts for interpretations. The present model is tested for various samples which are also presented and recognized that the output values are more précised in nature.

IV. ACKNOWLEDGEMENTS

We would like to address special thanks to our advisor, P.Srikanth for his personableness, support, advice and endless patience towards this work. I would like to express my gratitude to TIFAC-CORE and EED of NIT-H, India for providing the facilities required throughout this work.

TABLE II
OUT PUT CRITICALITY VALUES OF THE SYSTEM CORRESPONDING TO THE INPUTS AS IN TABLE I

O/P	J	K	L	M	N	O	P	Q	R	S
1	0.7	0.7093	0.5011	0.501	0.6345	0.5704	0.6012	0.8759	0.7	0.7
2	0.1367	0.1202	0.1241	0.132	0.1329	0.1361	0.1428	0.1141	0.1141	0.1275
3	0.25	0.1369	0.25	0.25	0.1928	0.3128	0.25	0.25	0.1141	0.1629
4	0.5	0.5	0.5	0.5	0.57	0.57	0.5939	0.5	0.523	0.57
5	0.8944	0.8805	0.8942	0.8821	0.7616	0.762	0.6748	0.8759	0.8323	0.7

J=Oil thermal, K=Paper thermal, L=P.D. electrical, M=Arcing electrical, N= DGA thermal, O=DGA electrical, P=DGA, Q=BDV, R=SFRA, S=Overall transformer.

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