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# A Novel Technique to Precise the Diagnosis of Power Transformer Internal Faults

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**Abstract** - Power transformers are to be monitored frequently to avoid catastrophic failures which are more or less related to internal faults for which many techniques and tools are developed, somehow many of these techniques rely on experts analysis and are well effected by environmental conditions which leads to misdiagnosing of the unit. In this paper a new fuzzy logic algorithm (FLA) based technique is developed which gives the vulnerability status of internal faults by considering thermal, electrical and mechanical conditions prevailing in the transformer and integrating them. This system takes a set of test results of dissolved gas analysis, break down voltage, and sweep frequency response analysis so that aliasing effects and misdiagnosing can be reduced at a glance. It also facilitates to give current prevailing condition of Paper thermal, Oil thermal, Partial discharge, Electrical arcing, oil break down voltage, and mechanical deformations related with core and windings individually so that corresponding remedies can be taken by the technologists. This system consists of 10 fuzzy logic controllers and is connected by considering technical conditions and reasons, the rule bases of these controllers were developed by considering various standards and experience of TIFAC CORE in NIT-Hamirpur. This fuzzy logic based system is tested and found that it is highly precise in classifying the critical statuses of any transformer, reducing misdiagnosing and aliasing effects and identifying the current prevailing conditions.

**Keywords** - criticality, fuzzy logic controllers, membership functions, transformers.

## I. INTRODUCTION

Power transformers requires a proper maintenance with an approach of efficient condition monitoring techniques and diagnostic tools. Precise 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 they relies more on experts 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 capability of insulating oil and paper during faults due to increased thermal and 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 hand break down voltage (BDV) of oil plays as an important parameter for determining dielectric 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

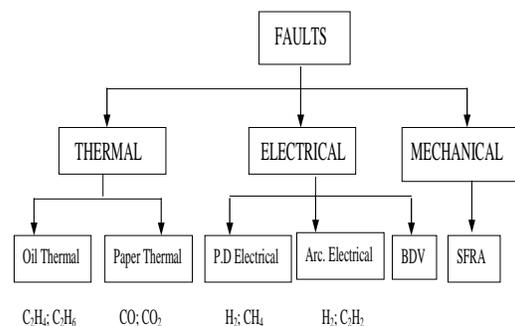


Fig 1. Classification of faults

Mechanical faults even have a major contribution to the internal faults which leads to severe losses to the unit and sometimes leads to outages. 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 a set of DGA [9], BDV, SFRA test values as inputs for which a repeating sequence block in matlab is used. SFRA is based on the evaluation of the curve obtained subtracting the present and the reference frequency response curve [10] while DGA, BDV are supplied as obtained from test results.

## II. FUZZY LOGIC ALGORITHM

The basic principle in decision making-process using fuzzy logic is as shown in fig 2 input variables are subjected to fuzzification which translates "distinct" input variables into "indistinct" fuzzy variables with the help of the membership functions. Rules are made using if-then-else conditions by which knowledge processing is carried out to relate the input variable to output variable,

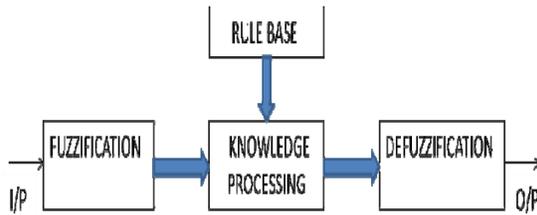


Fig 2. Basic principle of fuzzy logic algorithm

In knowledge processing, the indistinct fuzzy variables are logically combined (mainly AND, OR, NOT operations). The output is computed after defuzzification and calculation of centroid for which center of gravity or centroid method is used. 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, 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 the input variables and output variables [11]. The overall fuzzy logic model uses "Mamdani Fuzzy Inference System" (MFIS) and consists of 10 fuzzy logic controllers as shown in Fig.3.

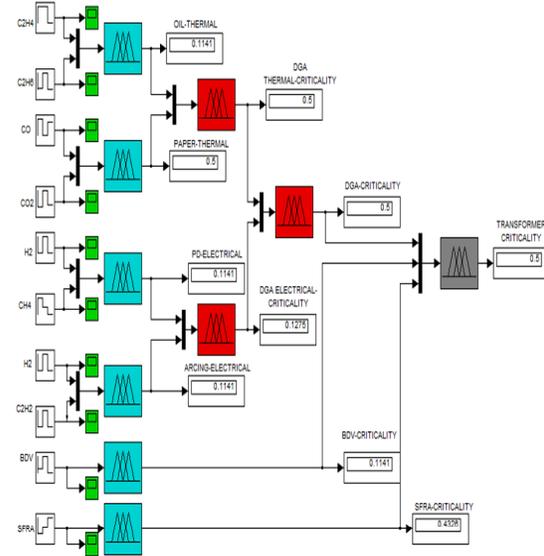


Fig.3 Complete fuzzy model for overall transformer criticality

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 exactly. One of these 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 paper thermal criticality is considered as it is known that carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) are evolved when insulating paper gets stressed and results to rise in paper temperature by reducing the heat dissipating strength of paper. A fuzzy system is developed for finding the vulnerability status of the paper temperature with considering a range of 0-1800 ppm and 0-15000 ppm for CO and CO<sub>2</sub> respectively. A set of obtained values of CO and CO<sub>2</sub> are given as inputs to the fuzzy logic controller as shown in

Fig.4 and a rule base is presented to the controller which on simulation gives paper thermal criticality.

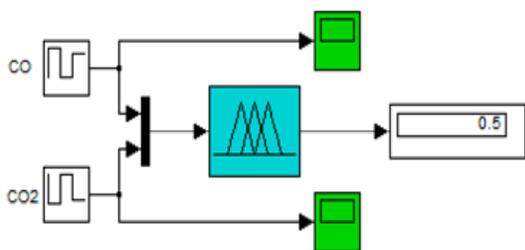


Fig.4 Fuzzy logic controller model for paper thermal criticality

Trapezoidal membership functions are chosen in developing this fuzzy logic model. Input and output membership functions are shown in Fig. 5, Fig. 6 and Fig. 7 respectively. If the DGA test is carried on a day with undesirable climatic conditions say it on a rainy day then the factors leading to misdiagnosing involves more and the values will be not according to the original prevailing conditions of the oil. Then if the test is repeated for a multiple number of times at regular intervals and if these couple of values are given to the repeating sequence block which presents inputs to the system.

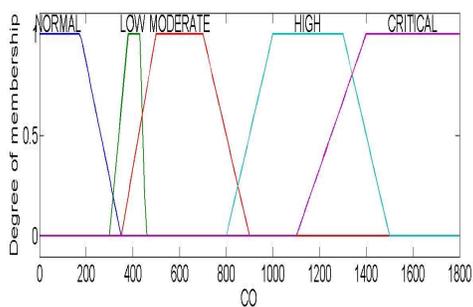


Fig. 5 : I/P Membership function plot of CO

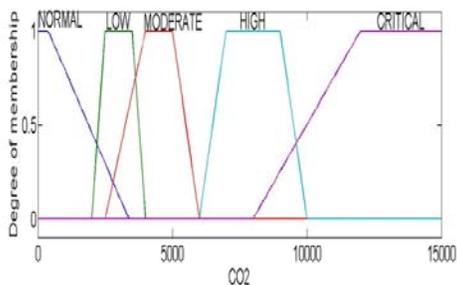


Fig.6 : I/P Membership function plot of CO<sub>2</sub>

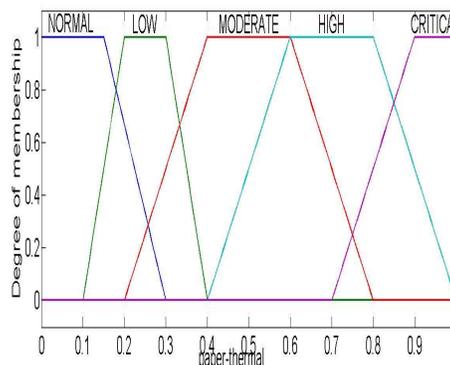


Fig.7 : O/P Membership function plot of paper thermal criticality

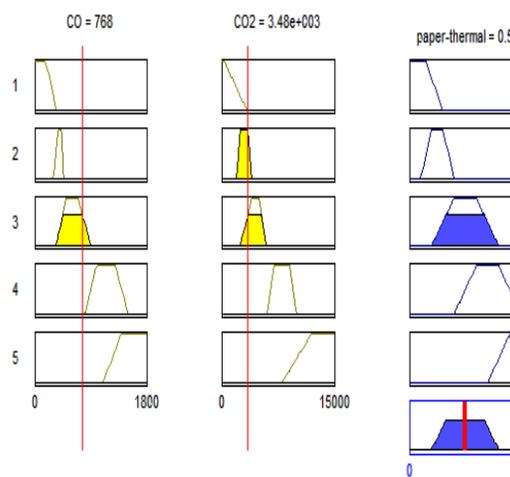


Fig. 8 : Rule viewer of paper thermal criticality

These inputs are read according the rule base developed using MATLAB / GUI for fuzzy inference system (FIS).Output membership function 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 CO<sub>2</sub> = 3705, 8185, 4034 and CO = 592, 358, 537 and a set of rules were developed which can be observed in rule viewer plot of the system in Fig.8. 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.The criticality can be more clearly judged by observing the surface plot of the subsystem as shown in Fig.9 below

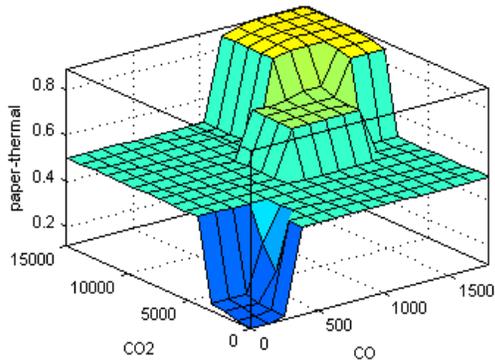


Fig.9 : Surface plot of paper thermal criticality

### 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<sub>2</sub>H<sub>4</sub>) on 0-200ppm, ethane (C<sub>2</sub>H<sub>6</sub>) on 0-150ppm, carbon monoxide (CO) on 0-1800ppm, carbon dioxide (CO<sub>2</sub>) on 0-15000ppm, hydrogen (H<sub>2</sub>) on 0-1800ppm, methane (CH<sub>4</sub>) on 0-1200ppm, acetylene (C<sub>2</sub>H<sub>2</sub>) 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. 0kHz 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 criticality level of transformer. A rule base is developed to correlate the input and output membership functions and is viewed as shown in Fig.10 below

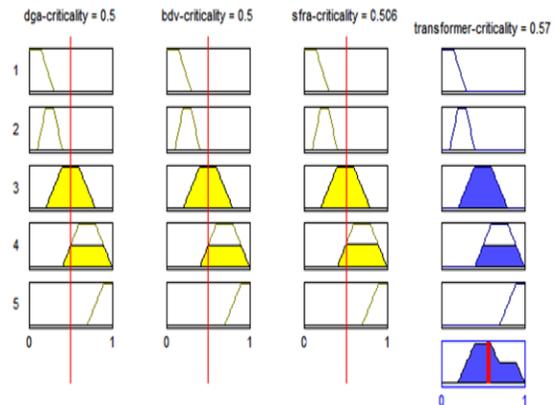


Fig. 10 : Rule viewer of transformer overall criticality

## III. SIMULATED MODEL TESTING - A CASE STUDY

This fuzzy logic model is simulated for different test sets 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 and are more precise in diagnosing the internal fault factors. For instance a case study is explained in detail. A transformer of 6.5 MVA, 6.6/33 kV is manufactured in

the year 2007 and commenced on 17-05-2008 has been tested on 19/20/21-07-2011 for DGA, BDV, SFRA and found no mechanical deviations, BDV as 46.32kV, 42kV, 45kV (according to IS-1866/2000) and on DGA interpretations according to IS-10593/1992 revealed that CO<sub>2</sub>, CO, C<sub>2</sub>H<sub>6</sub>, are in high levels 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: 0.1141
- e. Arcing electrical criticality: 0.1268
- f. DGA electrical criticality: 0.1275
- g. DGA criticality: 0.5
- h. BDV criticality: 0.115
- i. SFRA criticality: 0.1141
- j. Overall transformer criticality: 0.5

It is observed that insulating oil and paper are getting heated more with a criticality of 0.5 and 0.5 respectively, resulting DGA thermal criticality to 0.57 and P.D electrical is normal but 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.

#### IV. 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 in a more precise manner. 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 criticality 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.

#### V. ACKNOWLEDGEMENTS

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