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Fault Analysis in Power transformer using Integrated Fuzzy Controller with DGA technique

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Abstract: Transformer is a very important component of power system, now a days we are able to send power over long distance and at low cost only because of power transformer and at any cost Industries as well as customers cannot tolerate the failure of a Transformer for a moment. We use Mineral oil in transformer for cooling and insulation purpose. At different temperature different gases are produced in mineral oil of the transformer, so by analysis of these gases we are able to detect incipient fault in transformer and hence we have more time and chance for applying preventive maintenance in transformer. For analysis purpose of gases we use DGA method. Lots of techniques are given in DGA method for fault finding. All these techniques are computationally straightforward. However, these methods in some cases provide erroneous diagnoses as well as no conclusion for the fault type, so for this purpose we integrate a fuzzy controller with DGA technique.

Key words: DGA, Mineral oil, Fuzzification, Fuzzy Controller, Gas chromatography.

1. Introduction

"Transformer is the Heart and Vital equipment of Power System"

A transformer may function well externally with monitors, while some incipient deterioration may occur internally to cause fatal problems in later development. Nearly 80% of faults result from incipient deteriorations. Catastrophic failure of a transformer can result in protracted business interruption, particularly if the transformer is of an unusual capacity or size. A fire or explosion within a transformer can also threaten other essential assets or equipment on site or spread to neighboring property. Therefore, faults should be identified and avoided at the earliest possible stage by some predictive maintenance technique. Dissolved gas analysis (DGA) is a reliable technique for detection of incipient faults in oil-filled power transformer. It is similar to a blood test or a scanner examination of the human body; it can warn about an impending problem, give an early diagnosis, and increase the chances of finding the appropriate cure.

The majority of conventional power and distribution transformers in service in India are of Oil Natural Air Natural (ONAN) cooling type. Mineral oil performs two important functions in transformers. It cools the transformer and provides electrical insulation, as well. The analysis of insulating oils provides information about the oil, but also enables the detection of other possible problems, including contact arcing, aging insulating paper and other latent faults and is an indispensable part of a cost-efficient electrical maintenance program. When the mineral oil is subjected to high thermal and electrical stresses, it decomposes and, as a result, gases are generated. Different types of faults will generate different gases, these gases are detected at per part million (ppm) level and the chemical analysis of these gases, performed through a procedure called DGA (Dissolved Gas Analysis), will provide useful information about the condition of the oil, and help to identify the type of fault in the transformer. DGA requires the removal of an oil sample from the transformer, and this can be done without de-energising it. The oil sample is analysed in the laboratory using gas chromatography. Gas chromatography is a technique of separation, identification, and quantification of mixtures of gases.

2. Condition for Proper Transformer Sampling

Just like machinery oil analysis, the ability of insulating oil analysis to provide an early warning sign of a problem condition is dependent on the quality of the oil sample that is sent to the lab. As with sampling locations in other types of equipment, the same location should be used each time a sample is collected to ensure representative conditions are tested. This point should be located in a place where a live oil sample can be collected rather than in an area where the oil is static. Fluids with specific gravity greater then 1.0, such as askarels, should be sampled from the top because free water will float. For fluids with a specific gravity less than 1.0, such as mineral-based transformer oils, synthetic fluids and silicone oils, the sample should be taken from the bottom since water will tend to drop to the bottom in these fluids. There are a number of environmental variables, such as temperature, precipitation, etc., to consider before collecting a sample. The ideal situation for collecting a sample from an electrical apparatus is 95°F (35°C) or higher, zero percent humidity and no wind. Cold conditions, or conditions when relative humidity is in excess of 70 percent, should be avoided, as this will increase moisture in the sample. Collecting a sample during windy conditions is also not recommended because dust and debris enter the clean sample easily and disrupt accurate particle counts. If sampling the oils is unavoidable when the outside temperatures are at or below 32°F (0°C).The frequency of testing varies with the type, size age, and use of the transformer (Table 1).

Table 1: Frequency of Testing of a Transformer.

Rating	Application	Frequency of Testing(Months)
>1MVA	Furnace(high risk)	3
	Distribution(low risk)	6
	Special	3-6
<1MVA	Any Type	6-12

3. Mechanism of gas generation

The cause of gas generation is the breaking of the chemical bonds between the atoms that make up the hydrocarbon molecules of the mineral oil. The faults in the transformer produce the energy that is needed for breaking the chemical bonds. The gases generated include 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).

These gases, when generated, will initially dissolve in the oil. As more gases are generated, more will dissolve in the oil. However, there will come a point when the oil will be totally saturated with dissolved gas, and further generation of gases will result in their being released as they can no longer be dissolved by the oil. Lower amounts of energy or lower temperatures are required to create or break the C-H molecular bonds. Higher amounts of energy or higher temperatures are needed, to create, or break, in ascending order, C-C single bonds, C=C double bonds, and C≡C triple bonds.

Methane and ethane will form at lower temperatures because of the single bond (C-H and C-C). Ethylene gas will form at higher temperatures of more than 500° C because of the double bond (C=C). Even higher temperatures, of at least 800° C to 1200° C, are required for the formation of acetylene gas because it has a triple bond (C≡C).

4. DGA Interpretation

If an incipient fault is present in the transformer, concentration of gases dissolved in the oil significantly increases. A given gas volume may be generated over a long time period by a relatively insignificant fault or in a very short time period by a more severe fault. Once a suspicious gas's presence is detected, it is important to be certain whether the fault that generated the gas is active by calculating the total dissolved Combustible gases (TDCG) and rate of TDCG which is given by

$$R = ((S_T - S_0) \cdot V \cdot 10^{-6})/T$$

Where R is the rate (liters/day), S_o is the TDCG of first sample in ppm, S_T is the TDCG of second sample in ppm, V is tank oil volume in liters, and T is the time (days). The rate of generation of TDCG greater than 2.8 liters/day indicates that the transformer has an active internal fault and requires additional inspection by DGA methods.

5. Types of faults finding Methods

Many interpretative methods employ an array of ratios of certain key combustible gases as the fault type indicators.
These five ratios are :

A1 = C2H2/C2H4,
A2 = CH4/H2,

A3 = C2H4/C2H6,
A4 = C2H6/C2H2,
A5 = C2H2/CH4.

Rogers' method utilizes three ratios A1, A2, and A3. The method gives fault for the specific combination of these gas ratios. Dornenburg utilizes four ratios A1, A2, A4, and A5.This procedure requires significant levels of gases to be present for the diagnosis to be valid. The method gives fault after comparing these ratios to the limiting values.
Amongst ratio methods, IEC Standard 60599 is most widely used. It also utilizes three ratios A1, A2, and A3.
All these techniques are computationally straightforward. However, these methods in some cases provide erroneous diagnoses as well as no conclusion for the fault type. So, for this purpose we proposed to merge DGA and FUZZY LOGIC to enhance our ability for fault finding.

6. Normal values of dissolved gas

When mineral oil contains normal values of dissolved gas, it indicates no incipient fault in the transformer. Table 2 shows the normal values of dissolved gases in the oil. When the DGA results for all the seven key gases, are less than the values in Table 2, it can be concluded there are no incipient faults in the transformer.

Table 2: Normal values of dissolved gas in oil

Gas	Hydrogen	Methane CH_4	Ethylene C_2H_4	Acetylene C_2H_2	Carbon dioxide CO_2	Carbon monoxide CO
PPM	100	50	50	5	5000	200

The following should be considered as a guide only as different manufacturer's oil products will have different tolerances.

Table 3: Tolerance level of gases

Gas	Symbol	Normal	Abnormal	Interpretation
Hydrogen	H2	<150ppm	>1000ppm	Arching, Corona
Methane	CH4	<25ppm	>80ppm	Sparking
Ethylene	C2H4	<20ppm	>100ppm	Severe Overheating
Acetylene	C2H2	<15ppm	>70ppm	Arcing
Carbon Monoxide	CO	<500ppm	>1000ppm	Severe Overloading, Overheating in paper insulation
Carbon Dioxide	CO2	<1000ppm	>15000ppm	Severe Overloading

7. IEC gas ratio analysis

Three gas ratios are used in DGA - methane/hydrogen, acetylene/ethylene, and ethylene/ethane. The coding rule and classification of faults by the IEC method are given in Table 4.

Table 4: coding rule

Codes Range of gas ratios

Codes	A1	A2	A3
0	<0.1	<0.1	<1
1	0.1-3	0.1-1	1-3
2	>3	>1	>3

Table 5: Classification of faults by IEC method

Fault	Characteristic Fault	A1	A2	A3
F0	Normal Ageing (N)	0	0	0
F1	Partial discharge(pd) of low energy density	0	1	0
F2	PD of high energy density	1	1	0
F3	Discharges of low energy(D1)	1-2	0	1-2
F4	Discharges of high energy(D2)	1	0	2
F5	Thermal fault of low temperature(TL)<150	0	0	1
F6	TL between 150 and 300	0	2	0
F7	TL between 300 and 700	0	2	1
F8	Thermal fault of high temperature (TH)>700	0	2	2

Faults often start as incipient, low energy faults which may develop into more serious higher energy or higher temperature faults. When a fault is detected, it is important to determine the trend in the rate of increase of the gas. An increase in gas values of more than 10% per month above the normal values will indicate that the fault is active. It is also important to determine the trend in the occurrence of different types of faults, and to detect early, any deterioration towards a more serious fault.

8. CO_2 / CO gas ratio

When a transformer is overloaded, the paper insulation will be subjected to high temperature. Both carbon dioxide and carbon monoxide will be generated. When the normal values for both gases are exceeded, the next step is to calculate the CO_2/CO ratio. A ratio outside the 3 to 11 range will indicate a fault involving the paper insulation.

9. Diagnostic Procedure

The overall procedure of routine maintenance for transformer is listed in steps.
Step1: Collect the input data include concentration of dissolved gases C2H2, C2H4, C2H6, CH4, H2, CO, and CO2 of the sample.

Step2: Collect information such as tank oil volume, date of sampling, and date of installation of transformer is asked for further inference.

Step3: Calculates TDCG and compares with the standard permissible limits (IEEE standard, 2008). For normal level of TDCG (<720 ppm), permissible limits for individual gases are checked. The normal level of TDCG and individual gases indicates the satisfactory operation of a transformer.

Step4: If an abnormal level of TDCG or individual gas has been detected, determine the rate of generation of TDCG by analysis of the successive sample. For the normal rate of TDCG(less than 2.8 liters/day), further diagnosis is bypassed.

Step5: For an abnormal rate of TDCG, the proposed FIS is adopted to diagnose the probable faults.

10. Fuzzy diagnostic expert system

There are lots of indeterminate factors in process of transformer fault diagnosis whose influence to the transformer operation status is usually fuzzy and uncertain. Ratio codes are quantized to define the crisp boundaries of 0, 1 and 2. In practice these boundaries are non-crisp (Fuzzy) especially under multiple faults condition. These codes could lead to errors in diagnosis moving across the crisp boundaries from one fault to another. To overcome these limitations, Fuzzy System for diagnosis of multiple faults is developed.

11. Fuzzy set description

An ordinary set can be characterized as a binary function. Elements in the set can be assigned to1 and remaining elements of the universe can be assigned to 0. The function is generalized so that value assigned to the elements of the universal set located within a specified range which indicates membership grades of these elements within the sets, such function is called membership function and the corresponding set is a fuzzy set.

12. Fuzzy Interface System

Sugeno method is most commonly used fuzzy inference method.
A typical rule in Sugeno fuzzy model has the form,
if input1 =x and input2=y, then output z=ax+by.
The output level z of each rule is weighted by firing strength w of the rule.
For example, if input1 =f(x) and input2=f(y), then firing strength wi = AND method (F1(x), F2(y)),
Where F1(x) and F2(y) are the membership functions for input1 and input2.The final output of the system is weighted average of all the rule output which is given as,

$$\text{Final Output} = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i}$$

Where N is number of rules.

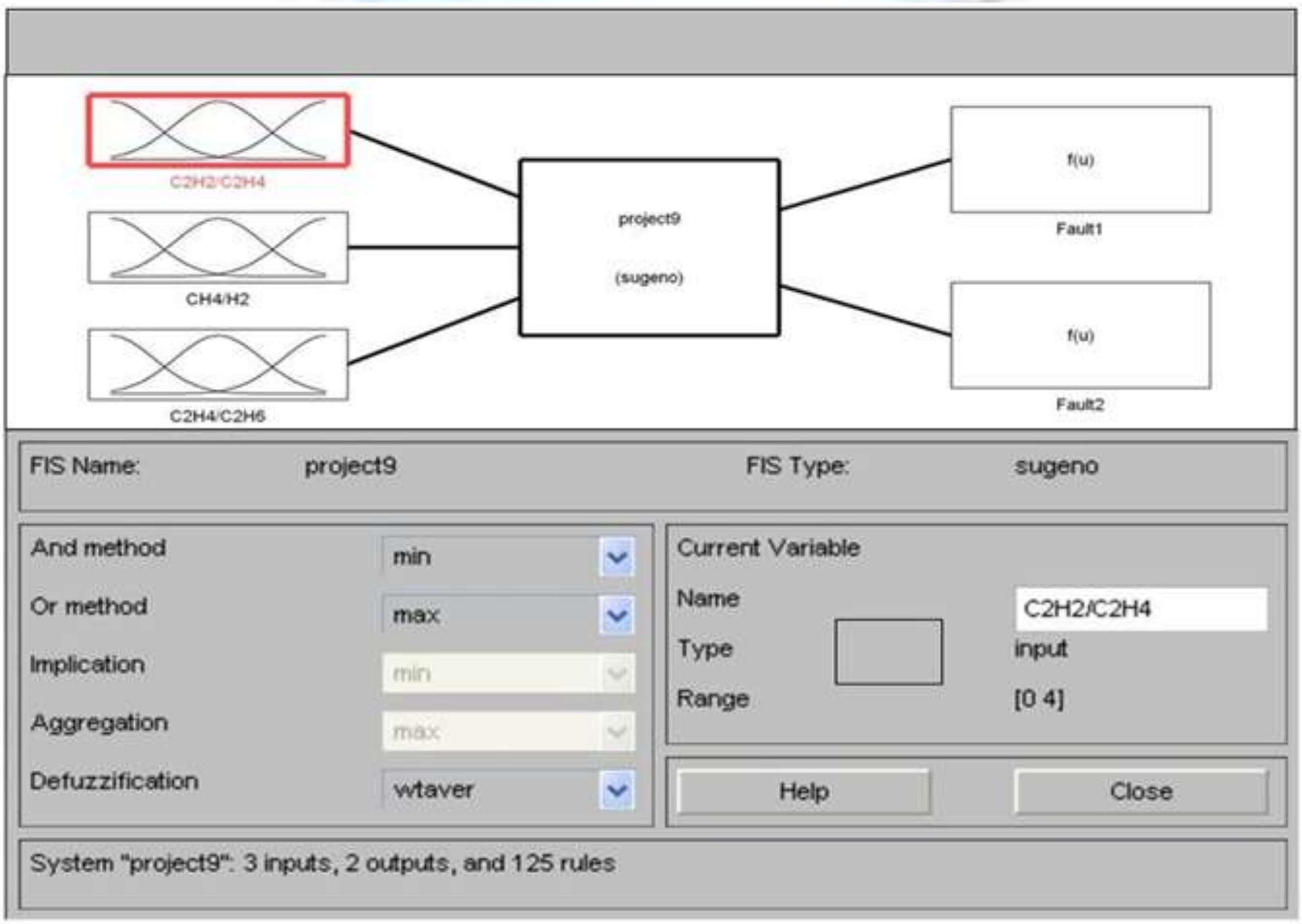

Figure 1: FIS editor prepared using MATLAB Fuzzy Logic Toolbox

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The fuzzy system consists of 3 ratios

C_2H_2/C_2H_4,
CH_4/H_2 and
C_2H_4/C_2H_6 as inputs. Each ratio is fuzzified as Very Low, Low, Medium, High and Very High according to membership intervals as defined in Table 5.

Table6: Membership intervals

Fuzzy Ratio	(A1)C_2H_2/C_2H_4	(A2)CH_4/H_2	(A3)C_2H_4/C_2H_6
Very Low	U<0.09	U<0.09	U<0.9
Low	0.09<=U<=0.11	0.09<=U<=0.11	0.9<=U<=1.1
Medium	0.11<=U<=2.9	0.11<=U<=0.9	1.1<=U<=2.9
High	2.9<=U<=3.1	0.9<=U<=1.1	2.9<=U<=3.1
Very High	U>3.1	U>1.1	U>3.1

The membership boundaries of Low and High fuzzy are fuzzified by using triangular function.

$$T(u; a, b, c) = \begin{cases} 0 & \text{for } u<a \\ (u-a)/(b-a) & \text{for } a <= u <= b \\ (C-u)/(c-b) & \text{for } b <= u <= c \\ 0 & \text{for } u>c \end{cases}$$

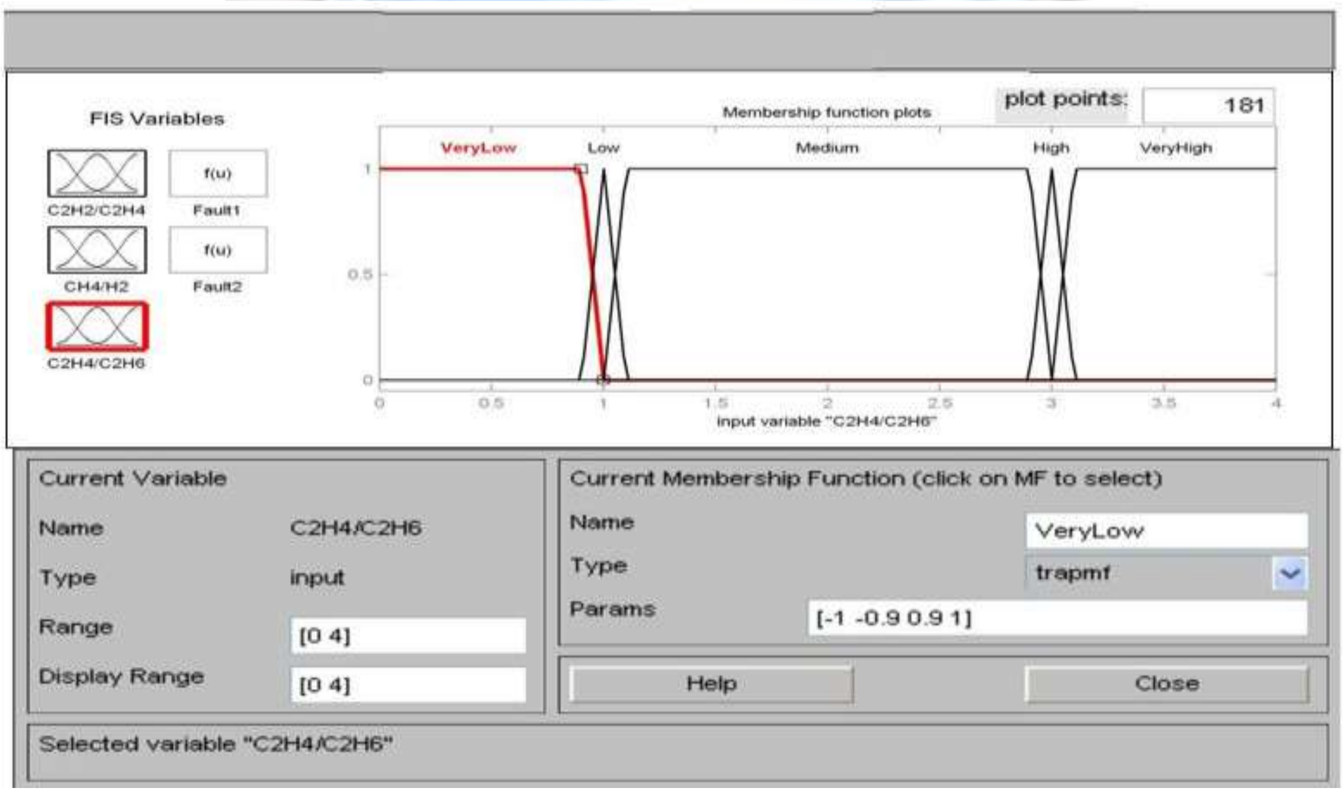

Figure 2: Membership function for C2H4/C2H6 ratio

The fuzzy system comprises of two outputs showing probable mixed faults. Each output has 09 Fault type as membership functions which is shown in Table 5. System comprises of 100 rules. Each rule consists of two components which are the antecedent (IF part) and the consequent (THEN part).With the fuzzy logic technique, the partial membership may improve the number of matched cases as compared to the ordinary crisp theory. Some examples of the fuzzy rules are shown in rule editor (Fig.3)

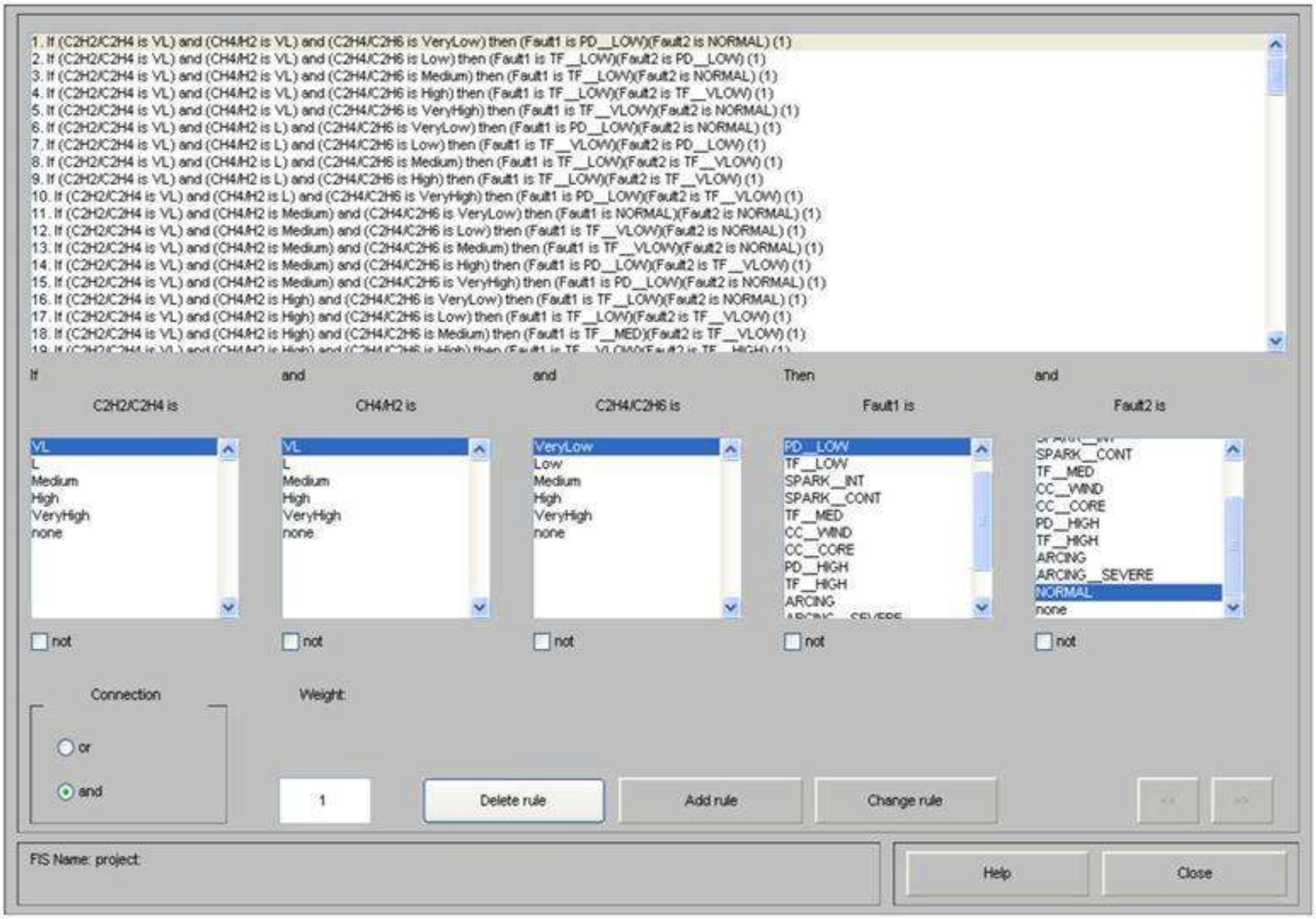

Figure 3 : Rule

Although the ratio codes rules appear strictly defined, borderline cases with gas ratios on or near the line between code 0, 1 or 2 allows fuzzy inference system to interpret membership function of these rules flexibly and classify these cases under two different fault types. In accordance with expert experience and field knowledge, severity can be assigned to each fault type. For the fuzzy logic control, Sugeno model is used. FIS derives output fuzzy sets from judging all the fuzzy rules by finding the weighted average of all 125 fuzzy rules output

Conclusion

DGA is a chemical rather than an electrical method. It does not suffer from electrical interference and can be done without de-energisation of the transformer. The cost of each DGA is relatively inexpensive. All these factors make DGA with fuzzy controller a powerful tool in the preventive maintenance of transformers.

Scope for Future Work

This work can be continued to expand the knowledge base by adding any new experience, measurement and analysis techniques. The combine result all DGA methods with fuzzy logic will be much more accurate than any single method with fuzzy. Further, this method is also applicable to other oil filled high voltage power equipment for assessment of its condition during the operating service period of time.

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