DGA based Condition Monitoring of Power Transformer

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Abstract
In the expanding world the demand of electricity is increasing day by day. The power utilities are making continuous efforts to reduce the gap between supply and demand. The effect of various faults in power system leads to unplanned outages in power system, which makes the situation still worse. Power transformers are the heart of power system. They are the key apparatus in power system. Any fault on transformer leads to unnecessary outages and huge loss to electric utility. For proper and reliable operation of power transformer, continuous condition monitoring is being required. From the last few decades, a lot of research work is going in the area of condition monitoring of transformers. Number of techniques are proposed by various researchers from time to time such as Dielectric Loss Angle (DLA or tanδ) of winding, Recovery Voltage Monitoring (RVM), Sweep Frequency Response Analysis (SFRA), Dielectric Frequency Response (DFR), Polarization Depolarization (PDC), Partial Discharge Measurement and Dissolved Gas Analysis (DGA) etc. Dissolved Gas Analysis (DGA) has got the highest attention and attraction from the researchers. DGA is used in oil filled transformers. The mineral oil in the transformers under the effect of various thermal and electrical stresses decomposes into number of gases compounds such as H_2, O_2, N_2, CO, CO_2, CH_4, C_2H_6, C_2H_4, C_2H_2 and C_2H_8. These gases are further analyzed to investigate presence of the fault in the transformer. A number of DGA interpretation techniques such as Dornenburg's Method, Roger Ratio Method, Duval Triangle Method, Nomograph Method etc. are available to investigate the gases evolved in the transformer. The accuracy and diagnosis of condition monitoring of transformers can be increased manifold by combination of conventional DGA interpretation techniques with the artificial intelligence techniques. This paper deals with Fuzzy Logic Model development to monitor the condition of power transformer. Fuzzy inference for condition monitoring using compositional rules have been designed and developed.

Keywords
Condition Monitoring, Dissolved Gas Analysis, Power Transformer Diagnosis, Fuzzy Logic

1. INTRODUCTION
Power transformer is one of the most critical and the costliest equipment in the system, failure of which can cause large disruptions in power supply [14]. The various weak links in case of a power transformer are winding insulation [11], bushings, tap changers, fans or pumps. Power sector utilities are making every effort to assess the internal condition of the equipment while in service before catastrophic failures can take place. The traditional calendar based maintenance is taken by condition based maintenance and it becomes the need of hour to explore new methods or techniques to monitor, diagnose and assess the condition of power transformer.

In the recent years this leads to the development of various on line and off line techniques that regularly diagnose condition of the power transformer to optimize the maintenance or repair schedules and thereby ensuring maximum availability and reliability of electric supply [12].

More attention and care is demanded by the power transformers which are approaching the end of their operating life than the newly installed transformers. The increasing failure rate of large power transformers is of great concern as they result in forced outages, increases maintenance cost and shortens life of transformer. For analysing the internal condition of transformer, it is necessary to employ the appropriate diagnostic tool [13].

PROBLEM FORMULATION

Many tools and techniques for condition monitoring and diagnosis of power transformers are available. The classical diagnostic methods have been used from past few decades; the results are worthwhile but not sufficient. Development of new methods and techniques provides much higher degree of diagnosis.

This paper deals with condition monitoring of power transformers. The suitable inputs are selected which mainly affect the condition of a power transformer. This information is then given to a Fuzzy Logic Model which monitors the condition of the power transformer and determines the condition of transformer. Fuzzy logic provides a robust inference methodology. Fuzzy Logic simulation is performed and the corresponding outputs are obtained. Fuzzy logic provides a very fast and precise inferencing. The limitations and constraints of analog condition monitoring having a large component of manual inferencing are thus overcome.

2. DISSOLVED GAS ANALYSIS
Dissolved Gas Analysis (DGA) is a method of diagnosing faults in electrical equipments having oil as an insulating medium. DGA is the vital technique used in condition monitoring of power transformers. Dissolved Gas Analysis provides the information about the fault well before the occurrence of fault, as it provides information about the growth rate of fault if the samples are taken at regular intervals of time [10]. It also helps in performing necessary actions well in advance so that the transformer can be prevented from occurrence of fault. The test data from DGA can be analysed to provide information about the transformer's recent operating conditions. It also provides information about incipient faults which are going to develop in a power transformer [2].

DGA helps in preparing maintenance schedule like when the next replacement or filtering of insulating oil is required. Dissolved Gas Analysis also aids in monitoring the rate of fault development in a power transformer. DGA is the most sensitive and reliable technique used for evaluating the condition of power transformer.

The insulating oil in the power transformers under the effect of various electrical and thermal stresses decomposes into various gas compounds [15]. DGA provides an indication of whether there may be active or incipient faults in the power transformer.

DGA is used to detect and quantify nine dissolved gases, which are H2, O2, N2, CO, CO2, CH4, C2H6, C2H4 and C2H2 [4],[7].

The following four steps are involved in the Dissolved Gas Analysis Method [9]:-

1. Collection of oil sample from transformer.
2. Extraction of gas from the oil sample.
3. Gas Chromatograph to quantify the individual gas concentrations.
4. Analyze the data.

The generation of specific gas in specific amount depends upon the nature and cause of fault. The test sample having different concentration of various gases obtained from DGA is further investigated by various interpretation techniques to draw conclusions about the condition of transformer. A variety of methods or techniques are available to interpret the result about the state of transformer. Some of the interpretation techniques are [1], [3]:-

a. Key Gas Method
b. Total Dissolved Combustible Gases Analysis
c. Dornenburg's Ratios
d. Roger's Ratios
e. Duval Triangle
f. Trend Analysis
g. IEEE C57.104
h. IEC Standard 605991

3. ROGER RATIO METHOD

In Roger's Ratio Method, ratios of gases obtained from DGA are used. Roger's Ratio Method makes use of knowledge from the Halstead's thermal equilibrium and Dornenburg's ratios, in addition, it also take into account the information from faulted units. The four inputs to the developed FIS model for condition monitoring of power transformer are CH4/H2, C2H6/CH4, C2H4/C2H6, and C2H2/C2H4 [8]. The output is diagnosis.

All these four inputs and one output have been taken on a relative scale for generic purposes. These inputs and output have number of fuzzy sets each. The output which is diagnosis in this case consists of eleven incipient fault conditions and a normal condition. The rule base used in the development of FIS model is based on the particular codes and the diagnosis condition of oil transformer is indicated in table I.

TABLE: I Roger's Ratio Codes [1]

CH_4/H_2	C_2H_6/CH_4	C_2H_4/C_2H_6	C_2H_2/C_2H_4	**Diagnosis**
0	0	0	0	Normal Deterioration
5	0	0	0	Partial Discharge
1-2	0	0	0	Slight Overheating less than 150 ˚C
1-2	1	0	0	Overheating 150 ˚C to 200 ˚C
0	1	0	0	Overheating 200 ˚C to 300 ˚C
0	0	1	0	General Conductor Heating
1	0	1	0	Winding Circulating Currents
1	0	2	0	Core and Tank Circulating Currents, Overheated Joints
0	0	0	1	Flashover without power follow through
0	0	1-2	1-2	Arc with power follow through
0	0	2	2	Continuous sparking to floating potential
5	0	0	1-2	Partial Discharge with tracking (Note CO)

4. FUZZY LOGIC

Fuzzy logic is a powerful technique for problem-solving with a wide area of applications in control system and information processing. Fuzzy provides a very simple way to make definite conclusions from vague, ambiguous or imprecise information.

In fact, fuzzy logic resembles human decision making with its ability to work from approximate data and find the solutions. Unlike classical logic, which requires a complete understanding of a system, exact equations, and precise numeric values, Fuzzy logic incorporates a way of thinking, like human which allows to model complex systems originating from our knowledge and experience. Fuzzy Logic allows expressing this knowledge with subjective concepts such as very hot, bright red and a long time, which are mapped into numeric ranges.

Fuzzy Logic is conceptually easy to understand, robust and flexible system which can work on imprecise data. Fuzzy Logic control makes use of fuzzy rules. The procedure for creating a fuzzy controlled model is followed by following three steps [6]:-

a) Fuzzification
b) Rule Evaluation
c) Defuzzification

Fuzzification involves describing the membership functions. Rule Evaluation involves the process of rule formation using the expert knowledge. Defuzzification means obtaining the crisp output obtained from the fuzzy data. Every rule process can be divided into conditions (the antecedent block) and a conclusion (the consequent block). If temperature is high then output is hot [5].

5. IMPLEMENTATION OF FUZZY LOGIC

In this section various steps involved in the fuzzy model development are discussed. Fuzzy model will extract expert knowledge of the power transformer regarding its condition under different working situations. The expert knowledge is then expressed in terms of linguistic form. The rules (IF THEN) based on expert knowledge are formed. In this paper we are using Mamdani based FIS system. There are four inputs and one output for the FIS. The inputs are gas ratios CH4/H2, C2H6/CH4, C2H4/C2H6, and C2H2/C2H4 as mentioned in table I. The membership functions and their ranges are selected for inputs and output. The inputs CH4/H2, C2H6/CH4, C2H4/C2H6, and C2H2/C2H4 have 4, 2, 3 and 3 membership functions respectively. The output has 12 membership functions which represent the condition of transformer depending upon the value of different gas ratios as per Roger's Ratio Method, as indicated above in table I.

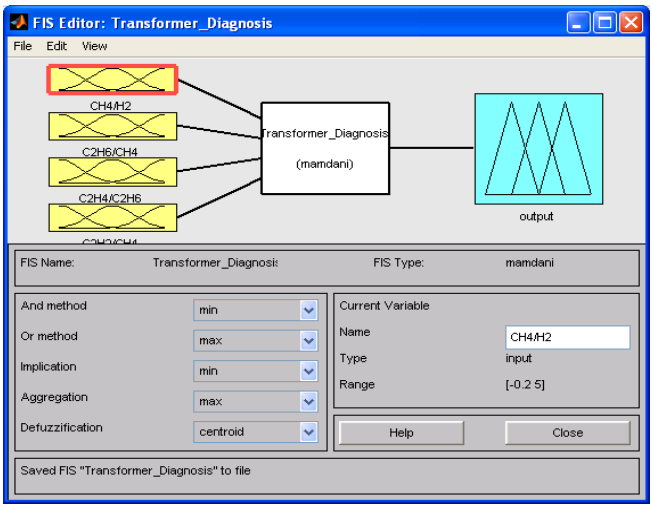

Fig. 1 FIS with four inputs and one output

The rule base is formed by using If (Condition) Then (Action) rules.

6. RESULTS

The results are obtained for different sets of inputs. If CH4/H2 = 2.4, C2H6/CH4 = 1.5, C2H4/C2H6 = 0.354 and C2H2/CH4 = 0.122 then output is 9.57.

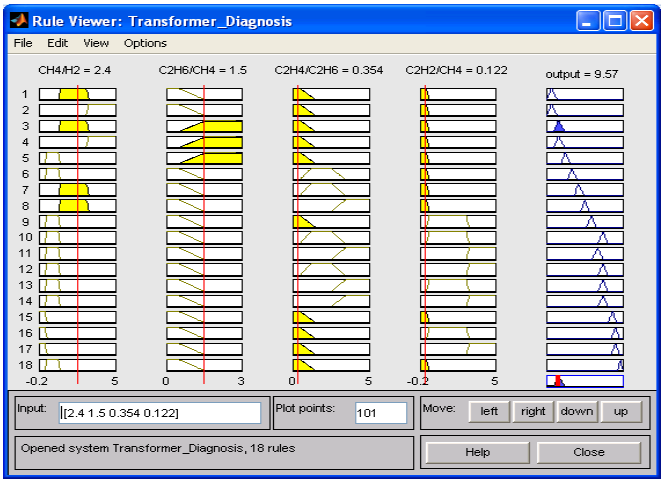

Fig. 2 Rule viewer indicating thermal fault output.

The output obtained from the fuzzy inference system indicates the presence of thermal fault in the power transformer.

7. CONCLUSION

In this paper a fuzzy inference system is developed to monitor the condition of power transformer. The inputs to the FIS system are the four gas ratios as taken by the Roger's Ratio Method. The use of fuzzy logic method leads to take advantage by providing results without using complex calculations and less time. Roger's Ratio method is used for interpretation of fault types from the DGA test data obtained from the transformer. Due to lack of availability of practical DGA data only some cases have been considered and tested for the classification of fault by the developed FIS model. The results obtained are of high accuracy. More test samples of DGA may be considered to make the FIS system more efficient.

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